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WORLD POWER AND ATOMIC ENERGY

The Impact on International Relations

Also by H. E. Wimperis

AVIATION (*Home University Library, 1945*)

"BABY PLAY WITH NICE BALL?"

DAVID LOW CARTOON OF 9 AUGUST 1945

[*Frontispiece*

H. E. WIMPERIS

WORLD POWER AND ATOMIC ENERGY

The Impact on International Relations

"Peace unbacked by Power remains a dream"

FIELD-MARSHAL SMUTS

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PREFACE

THE door of Creation's great storehouse of atomic energy has been forced and stands ajar. Nothing since the discovery of how to make Fire has so added to Man's physical control over the forces of Nature.

An immediate and dramatic consequence was the final blow it gave to the already tottering power of Japan. This shook the whole world, not only for its immediate and very evident effect on human affairs, but because of the indication that here was a new source of mechanical power which might have an influence as wide-spread as beneficent in almost every aspect of civilised life.

On the exceedingly important—indeed vital—problems thus raised public opinion is now in process of formation, and although there can be little finality about conclusions drawn at this early date, some preliminary decisions must be made, and made quickly. Considerations scientific, engineering, and ethical are alike involved.

"If we could first know where we are and whither we are tending," as Abraham Lincoln once said, "we could better judge what to do and how to do it." A modest step was taken towards this necessary work of preparation in the survey I made, at the invitation of the Royal Institute of International Affairs, of "The Impact upon International Relations of the New Weapons," published in their journal, *The World To-day* (Sept. 1945).

That study had to be limited to a few pages, and it is my purpose in this book to expand the survey sufficiently to make it of assistance to our present discussions. With

the facts fairly presented, as has been my endeavour, readers have the material on which to base their own judgements, and their actions, as to the policy which our Government, with others, should follow.

We face a great moral issue, a challenge to all that is best in us. By old custom we, as the challenged, have the right to choice of weapons. Shall the choice be another weapon for war, deadlier than all before, or a tool which in the right hands can do much to aid in world reconstruction and add to the peaceful amenities of life? Either may be chosen, both we cannot have.

For permission to reproduce his timely cartoon on atomic energy I am indebted to Mr. David Low and to the Proprietors of *The Evening Standard*. I acknowledge also the use made of information in three official publications: the American report on Atomic Energy by Dr. H. D. Smyth; the Canadian one from their National Research Council; and the British White Paper containing "Statements Relating to the Atomic Bomb." In these three reports a somewhat different frontier line is drawn between what is told and what is not—so that from the several pieces a composite picture has to be drawn. But for that composition I take sole responsibility.

Not less must I express my thanks to Sir Charles Darwin and Sir George Thomson, both experts in this field, for letting me quote from the published lectures of which they were kind enough to send me copies.

My friend Mr. H. E. Piggott, formerly of Clare College, Cambridge, has been kind enough to read the proofs, and to offer many suggestions which I have been most glad to accept.

H. E. WIMPERIS

14 *February* 1946

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ILLUSTRATIONS

The Frontispiece, a cartoon by David Low, *is reproduced by kind permission of* The Evening Standard. *The Diagrams illustrating the German Robot Weapons and the American Atomic Bomb Plants appeared in* The Engineer *and are reproduced by kind permission, respectively, of* The Ministry of Information, *and of* The United States Information Service.

CHAPTER I

INTRODUCTORY

WITH the release over Japan in 1945, on August 6, of the the first atomic bomb used in war the course of history was changed. Nothing in the relations between sovereign States could ever be quite the same again. Equally changed will become the sources of power for industry, transport, and domestic amenities once the problem of releasing atomic energy gradually, instead of explosively, has been solved. There are thus two distinct fields for the use of atomic power—the military and the domestic. They rest on the same foundation of scientific knowledge; but they are likely to call increasingly for diversity in methods of manufacture.

The discovery of an explosive many thousand times as powerful as anything hitherto known is a menacing addition not only to the military power of bombing aircraft, but, especially, to that of the long-range robot weapons. The effect upon the relationship of States to each other has to be thought out afresh, and the new situation, whatever it is, squarely faced. Obviously an immense impulse is given towards the creation of a World State; but that must take time. Fortunately we have in the throes of creation a new almost world-wide United Nations Organization with a Security Council acting under it having the duty of preserving world peace. It is now possible, should it be so desired, to arm that Council with the most potent weapon ever discovered by man.

The Council would in any case have had an urgent task in the control of such weapons as the flying bomb

(V1) and the rocket (V2). That urgency has grown mightily through the discovery of the uranium explosive which can arm either. Its responsibilities may grow even greater, in the days to come, with the use of the uranium reaction to provide a greater source of mechanical power than any we now know.

President Truman has spoken hopefully of the time, perhaps not far off, when atomic energy will supplement the power derived from coal, oil, and waterfalls; this will prove of immense value to those countries all too scantily provided. The same point of view was expressed in a special article in *The Times*: * "To-day he who is plaguing himself about the exhaustion of the coal and oil fields of the world in the next 100 years can, indeed, have few genuine cares." It must nevertheless be borne in mind that in so far as success crowns these efforts, so, with this new fuel, the potential destructive range of operation of all warlike weapons will, unfortunately, be increased and we may have to face the likelihood that any spot on this globe will be capable of being reached by one or other of these weapons; their potentiality for destruction may indeed be many thousand-fold greater than that of the rudimentary forms of these unpleasing devices which we knew in 1944 and 1945.

This is a challenge indeed! What is to be the reply? To any virile race there can surely be but one: to accept the challenge; to take up with zest the great task of meeting it, with the conviction that we can and will eliminate sternly any use of these new powers on the part of any persons tempted to seek world domination; and to draw from this heaven-sent opportunity the very best of the great benefits it can confer on the whole world. It has been bravely suggested by Prof. Bernal † that

* 8 August 1945.
† During a broadcast discussion in September 1945.

when the economic possibilities of atomic energy are made known and developed, the effect on human life may be such as to remove altogether the economic rivalries which, in the unhappy past, so often led to world strife. In so far as wars originate from those causes, that may prove an attainable prospect; the uncertainty is whether the evil desire for domination for the sake of domination will also be removable by happier conditions of life. We trust this will prove so, but it is necessary to face frankly here and now just what are the dangers inherent in the possession of this new vast power, as well as how best to harvest the benefits it undoubtedly offers. It is true that at the moment we are more keenly aware of the dangers than we are of the benefits. Hence the gloomy letters from the faint-hearted which have appeared in the daily press. But although the way to adapt atomic energy to industrial and economic use has yet to be developed, and the cost of producing it has still to be ascertained, it may be but a few years before this is attained. Hence it is most desirable that we should be able to picture what that prospect is likely to mean in reality, and be ready with well-considered plans to take advantage of the position.

Our own Government, in order to ensure that the right action shall be taken, has appointed an "Advisory Committee on Atomic Energy" under the chairmanship of a keen administrator, Sir John Anderson. We need be in no uncertainty as to his personal views on this vital question, for, speaking in London in September 1945,* he said: "I am concerned, and very much concerned, with the impact of the atomic bomb on human society. . . . We have, I think, been rather slow to grasp the full implications of this momentous development." He pointed out that a world peopled by men who

* *Sunday Times*, 30 September 1945.

have atomic energy at their disposal must differ from all we have known before, and that a complete readjustment of international relations was called for—indeed a new order of society. He added: "What is of vital importance is that the nations of the world should get down to this problem without delay. If there is delay, incalculable mischief may be done. There is a real risk of blunders being committed in the decisions at which the great nations of the world will have to arrive within the next few months." This makes clear the immediacy of the issue. The problems raised are fundamental, and public opinion needs to have all factors bearing on the problem placed clearly before it.

We know that many countries shared in the task of laying the scientific foundations on which all this work has been built. That foundation was, however, on the small scale appropriate to laboratory investigations, and its extension to full-scale operation called for an immense amount of additional research by the ablest scientists and engineers available in America, Britain and Canada. This was successfully achieved during the war years. Much the greater part of the immense expenditure was borne by the United States Government, and all the huge full-scale plant which had to be provided is in that country. How far and under what conditions America will be willing to pass on that great body of knowledge to others—even, for instance, to the United Nations—is primarily a matter for decision by that Government, in consultation, no doubt, with those of Britain and Canada; it will help if it becomes convinced of the whole-hearted support of the United Nations Organization throughout the world, and of a widespread will to use it to the best advantage of mankind. There is reason to hope that the Security Council acting under that Organization will be found to command that degree

of confidence, and perhaps be ready to agree that the manufacturing plants in America shall be the source of any atomic explosives needed for the Council's military requirements, if the United States Government were willing to act as Trustee Power to the United Nations Organization for that purpose. As the manufacturing technique for civil requirements is likely to develop on different lines from that needed to meet military ends, there will, it is hoped, be no reason why all countries should not develop where they will the use of atomic energy as a new form of fuel.

At one stage of the war-time investigations it became evident that a certain line of experiment would, if further pursued, lead to a flow of energy from uranium so gradual as to be useless for the immediate purposes of war. That line of experimentation, although abandoned at the time, gives support to the view of scientists who believe that atomic fuel may become available in a comparatively few years.

In October 1945, President Truman sent to Congress his first message on the subject of Atomic Energy.* He pointed out that to accomplish the aim of using this source of energy for human welfare it was needful to think of two aspects—the domestic and the international. Dealing first with the former, America, he considered, could not postpone a decision on the domestic policy of the right control and use of atomic fuel. The supply of the appropriate raw materials must needs be investigated and controlled: Congress should provide for the future of existing manufacturing plants and control their development. A Commission should be authorized to conduct the necessary researches to the end that the fullest use should be made of this new source of power. The President proposed to initiate discussions first with

* *The Times*, 4 October 1945.

America's associates in the discovery (this has since happened), and then with other countries, in the hope that it would be possible to establish satisfactory conditions in which " co-operation might replace rivalry in the field of atomic power ".

It will be the aim in the pages that follow to deal frankly with the warlike menace not only as it exists but as it might easily become if unchecked; to survey briefly the general nature of the scientific basis of this work and the abundant promise it holds for a vast increase of economic and industrial prosperity; and finally to stress the need for control in all its aspects by responsible authority.

CHAPTER II

THE MENACE IN WAR

WE control the mightiest explosive ever known, and will soon, perhaps, possess a richer storehouse of fuel than any present source of mechanical power. Either can be used for war; and if they are there is no city so remote as to be free from the liability of attack.

The risk of an intensification of such perils by this use of the energy hitherto so securely locked in the atom is apparent to all. If our use of it is foolishly conceived, few may remain to enjoy its benefits! This is a danger against which we must be on guard; but before discussing the highly intricate question of the control of this new force, and to provide the appropriate background for inquiry, it is necessary to consider just what the danger is, and how it arises. So in this chapter the terrible potency of the uranium explosive for use in war is described.

Like all other explosive material, it needs, to produce its effect, some form of carrier to convey it to the selected target. It might, it is true, prove capable of being used in artillery; but it is its conveyance by aircraft, manned or unmanned, and by rocket that gives rise to the chief menace. For by its means the striking power of bombing aircraft, and especially of robot weapons, such as the V1 and V2, can be multiplied many thousand-fold. Not only would their destructive power be thus immensely increased, but by the use of atomic fuel, when it comes, the range of action of each of these weapons would extend to the entire surface of the globe. Hence the field to be surveyed is world-wide.

Since it was as a war measure that the large-scale release of atomic energy was first effected, it was natural that its first practical application should have been to a warlike purpose: indeed, the tremendous effort that effected its release was intensively directed to that very end, and no other. Its possible use for civil purposes was, intentionally, left aside. (As it happens, the release for explosive purposes proved to be a far simpler task than that for its use as a fuel.) The work of the scientists and engineers needed to make this war-time achievement possible would no doubt have been carried out in any event at some date, war or no war; but, without the stimulus of national emergency, that date might, and probably would, have been far ahead. In later pages the story of this rapid technological advance will be described—so far as at present released and to such extent as is necessary for our purpose.

We can now produce at will an explosive many thousand times as powerful as any hitherto known; in time of war, its knowledge being available alike to all, its use would prove devastating to both sides. For we must reckon with the growing use of aviation as an effective and speedy carrier; as well as with its employment in rockets. Even with aircraft alone, the attack could be made over distances measured in thousands of miles. In the recent war, bomb-loads—even single bombs—of 10 tons weight were carried for hundreds of miles into enemy lands. Since a 25-ton bomber can fly about one mile on each gallon of fuel, it could cover 300 miles for each ton of fuel, so that for a return flight of 3000 miles, the fuel would be about as heavy as the bomb-load itself. If a single atomic bomb were carried instead, the explosive load, for an even greater destructive power, would be almost negligible in comparison; and at once the possible operational range would be doubled. Whilst, if atomic energy became

available as an aircraft fuel, the striking range would be still further enhanced. All bombers would, however, be liable to air and ground attack from any target vigorously defended. To saturate the defence, a very large number would be needed, and this would no doubt be provided by constructing, in large numbers, the quickly made robot weapons, such as the V1 with which we became all too familiar in recent years. For effective use they would need to be so designed as to reach a higher state of operational efficiency than V1 ever reached. It is useful therefore to consider where the V1 failed, and why its successor, V2, fell so far below its originator's expectations.

The Flying Bomb (V1)

Since, by ordinary usage, the word "aircraft" means a winged apparatus of some sort, it would not normally be held to include wingless rockets. But the line is hard to draw, for, as will be shown, some experimental rockets were planned with wings, so that at their crest height, or at some later stage, they would be able to pursue a long, gliding path to their targets, and thus achieve a considerably increased range. In such cases the one weapon merges into the other, but normally one regards a weapon like V1 as an aircraft, and a rocket like V2 as not.

The very first pilotless bombing aircraft were made in America. The occasion was the 1914–18 war; but that ended long before any use was made of them. Those I saw at the time in America were not very different in size from the V1, but were powered by a piston-type engine, of simple and cheap design, just good enough to last for the one operational flight it would make. Some years later, Britain decided to design and build pilotless aircraft, not, however, for use as robot bombers,

but with the object of producing unmanned flying targets for use in anti-aircraft training. This device, besides being gyro-stabilized, was controllable in flight by the use of simple radio apparatus; it could be made to land itself, if—as often happened in the early days—it survived the day's firing practice. It was plain, of course, that such a device could easily be converted, if desired, into a flying bomb, and various schemes for so doing were put forward by ingenious persons. But such bombs would be bound to suffer from inaccuracy of aim, which the vagaries of the weather would ensure, whilst having no means of defence or power of manœuvre, they would be vulnerable to attack from ground and air. If this inaccuracy in aim was sought to be lessened, or even removed, by radio control from the base, the counter-measure of radio-jamming was always available to the country attacked, and this would become the more powerful the closer the missile got to its target. If, as an alternative, reliance were placed on even the most ingenious form of navigational dead-reckoning, it would be impossible to avoid errors arising through ignorance of the appropriate wind corrections when the missile had covered some hundreds of miles from its base. It is not surprising, therefore, that the flying bomb was not adopted by the Allied authorities, strongly averse as always to the adoption of weapons whose only use could have been to spread terror and damage among the general population.

It was revealed in a statement made in September 1944 by Mr. Sandys,* then Chairman of a War Cabinet Committee, that in 1943 warnings had been received that Germany was developing secretly for use in the war a long-range bombardment weapon of a novel type. This turned out to be just such a small, pilotless

* *The Engineer*, 15 September 1944.

bombing aircraft as that described, but jet-propelled. A few months later it was noticed that a series of concrete structures, increasing to over 100 in number, were under construction along the French coast, and that most of them were oriented on London. These were immediately attacked from the air, and so successfully, as we afterwards learned, that the enemy time-table was upset, and many precious months of time were lost to him. As a consequence, the bombardment of Britain by V1, when it came in June 1944, lasted only some eighty days; and of the 8,000 of these missiles aimed at Britain, many crashed in France, or into the sea; even more were destroyed on their way by ground and air defences, and only 2,300 reached the London region. London was the main target for all these attacks: in fact, of all V1 fatal casualties, 92 per cent occurred in the Metropolitan area.

The V1 was about 25 ft. in length, with a span of 17 ft. The speeds attained in practice were 300 to 350 m.p.h., with a range of some 150 miles; the weight was just over 2 tons, the warhead carrying about a ton of explosive. The engine was of tubular form, highly ingenious, though most wasteful of fuel; it was of an impulse jet type with rapidly following explosions (like those in other internal-combustion engines) at 47 cycles a second, about the musical note given by an organ pipe of the same length as the engine itself—as no doubt its able designer intended. Equal ingenuity was shown in the launching arrangements, in which the propulsive power was derived from the reaction of "T. Stoff" and "Z. Stoff" (hydrogen peroxide and calcium permanganate): a highly novel method of producing steam pressure.

At the other end of the so-called "Axis", the Japanese also produced a flying bomb—the "Baka"—but characteristically replaced the automatic mechanism by a

human suicide-pilot, thereby greatly limiting the scale on which it could be used.

As already stated, the flying bomb was no novelty; what was new was its operational use in time of war. Although numbers of them were made for experiment in America during the first World War, that does not mean that had that war continued they would necessarily have been used operationally. The purpose of the experiments was to discover the potentiality of the device—and no doubt its cost in man-hours—the next step would have lain with the War Staffs of the day, who would have the duty of deciding whether it would be sound policy to use them or not. Any attack they made could hardly fail to be largely indiscriminate, and against such a use there are both moral and material arguments. The moral argument is too obvious to need discussion here, but on the material side it would be natural to ask whether a piloted bomber would not be more efficacious in relation to the man-hours consumed in production—for the losses of the flying bomb would, in the nature of the case, be 100 per cent, as against 5 per cent or less with the bomber. Opinion in the R.A.F. was always averse to their use, and that opinion was no doubt wise; nevertheless a bandit Power such as Germany was quite willing and ready to use them; so they might conceivably be used some day again—given the chance. Certainly if Germany could have succeeded in deluging London to the extent that we now know she intended, its centre would have had to be evacuated, and perhaps its suburbs too. But such action would not have ended the war, nor, indeed, could it have come so near to doing so as the assiduous and accurate use of manned bombers in the manner of our own attacks on Germany.

Although the flying bomb of 1944 was not unlike its 1918 predecessor in respect of size and range, an im-

portant difference lay in the use by the Germans of jet propulsion. Neither engine nor airframe was expensive to produce; indeed, the whole weapon with its ton of explosive probably cost no more than a light car; whereas according to one estimate the rocket which followed it may have cost as much as one of our own Spitfires, and according to another about as much as a twin-engined bomber. The flying bomb was exceedingly extravagant with fuel, for, despite its tiny size, it used as much fuel per mile as a full-loaded Lancaster bomber: nor was it at all speedy. It looks, indeed, as though its German designer must either have been curiously insensitive to operational requirements, or else—which is more likely *—was baulked by some technical hitch which could not be surmounted in the time imposed by authority. We now know how disregarding was the German High Command, at the "Highest" point especially, of advice from its own technicians. Lack of harmony between Operational Staffs and aircraft designers seems to have been strangely and fatefully common in Germany during the war, especially towards its end. Persons overshadowed, as many were, by the fear of some action by an unscrupulous police force rarely work at their best.

It would have been easy, given time, to have endowed V1 not only with substantially higher speed but with far greater range; any bomber able to fly the Atlantic could carry an automatic pilot, be filled with explosive, and despatched across the ocean. Hence a range of even thousands of miles was at all times practicable. But the path it flies is subject to the vagaries of the weather, and accuracy of aim could only be achieved if

* Perhaps more likely still, the German High Command tried the V1 against such Spitfires as they had captured, forgetting that by the time the attack began there would be later Spitfire models available for the defence.

it were continuously guided from a radio station at a home base, or from an accompanying aircraft. As has already been stated, radio control is easily jammed, or deceived, and the nearer the weapon to its target, the truer this becomes. With the new use of uranium as the explosive, extreme accuracy of aim would be of less consequence, but even at the best—or worst—it would be mainly a terroristic weapon—which devices, though certainly a grave nuisance, do not win wars. "In assessing the value of any missile", as Lord Cherwell said in a debate in the House of Lords, "we must take into account not only the damage which it can do if it hits, and its range, but also its chance of hitting a worthwhile objective, and the effort in man-power required to produce and project the missile."

Perhaps the best that can be claimed for the operational use of V1 is that it did "lock up" hundreds of thousands of men and women in the Services who gave us protection against it. How excellent and efficient was that protection is revealed by the fact that towards the end of the flying-bomb attack as many as 76 per cent were being destroyed by the defences, a large proportion of them while still over the sea.

The Rocket (V2)

It was after the loss of the French coast in August 1944 that the Germans brought into operation their long-range rocket. This was about five times as heavy as the flying bomb, but carried no heavier charge. Nor were the operational ranges very different. What the Germans expected of the rocket is not yet quite clear, but it seems that they counted on its being almost impossible to intercept, and that it flew so fast (about a mile a second) that no local warning would be given

of its impending arrival, for it flew much faster than sound. Of its starting weight of some 12 tons, as much as 8 tons was fuel, the warhead 1 ton, and the rest structure and mechanism. When about to start from its base, it stood up vertically on its tail and was propelled with an upward push from its powerful jet of exhaust gases with a force estimated to equal that of five express railway locomotives. The fuel was burnt in about a minute, by which time the rocket had attained a height of about 20 miles, the initial vertical path gradually changing, by the action of internal mechanism, to an angle of 45 degrees or so, that being the angle for maximum range. At the great heights attained, most of the Earth's atmosphere was left behind, and the projectile proceeded on the parabolic path familiar to the schoolboy. A maximum height of about 60 miles was reached, with a range of 200 miles or a little more. (The height reached with such missiles is always about a quarter of the maximum range: for an unresisted path, above a flat Earth, it would be precisely one quarter.) Many failed to function rightly—on the average 1 in 5—and fell back on the Dutch coast, to the great hurt of The Hague and other towns, and many ended in the sea. Oddly enough, one of the latter was seen by a very distant observer (myself, as it chanced) as far away from Holland as is London, to start on its path from The Hague. That such a "long view of a V2", as it was described in *The Times*,* was possible may seem surprising, but the atmospheric conditions were unusually favourable. The time was half an hour before sunrise on a late autumn day in 1944. Chancing to glance from a small easterly window, I was astonished to see (thanks to a conveniently placed gap in the built-up skyline) the bright ascending trace of a V2. A plot of the observed

* *The Times*, 12 December and 19 December 1945.

bearing on a map showed the line to go straight from London to The Hague, and inquiry in the right quarters confirmed that this was a long view of a V2 starting on its westerly course—in this case happily ending in the sea. The exhaust trace, brilliantly lit in its upper part by the still-hidden sun, then rising some 200 miles east of The Hague, stood out against the dusky sky, and so was seen to its extreme height of 20 miles, though the lower 6 miles or so were below the horizon. Beyond this height of 20 miles no trace was visible, as the fuel had by that time been burnt.

Another observer saw the fall of the rocket which damaged the Royal Hospital in Chelsea: and described it as a " red-hot telegraph pole ". This alarming appearance was due to the casing becoming red hot by the compression of the air, aided by air friction, and its apparent considerable length was accounted for, no doubt, by persistence of vision. The heating of air which arises from sudden compression is well known. The familiar example is the bicycle pump: there the heating is partly due to air compression and partly due to wall friction—just as in the case of the rocket. The temperature of compression is easily calculated, and on the nose of a moving body is known as the stagnation temperature (since it reaches its maximum when the air stream is at rest relative to the body). In the case of V2 this temperature is over 1,000 deg. Cent., and it is at its highest over the shell of the warhead. It was the heating of the shell which caused so many to explode long before reaching the ground, and it presents a real problem to any designer aiming at longer ranges, and therefore at higher speeds of propulsion. The temperature is quadrupled when the speed is doubled.

It was long before the late war that the use of great rockets as an alternative to bombing aircraft occurred to

the minds of the German Military Staff, and as it was physically impossible to conceal experimental work on this project, it was allowed to be understood that the object was inter-planetary transportation. Why people should wish to start on journeys to other planets was not explained. Although the starting might not be difficult, once certain technical obstacles had been overcome, a safe landing on the surface of the selected planet might well prove exceedingly hazardous. Moreover, the provision of equipment for starting the return flight would have its own problems, to say nothing of ensuring a correct aim at Earth and a safe landing outside the ocean area, which constitutes two-thirds of its surface. One may say that although a successful start was not impossible, a safe return would be exceedingly unlikely. Many people, if pressed, would perhaps find it not too hard to draw up a short list—or even a long one—of suitable passengers, but few would be likely to include their own names!

Some work of a purely scientific nature was done in America: with that the name of Professor Goddard, of Clark College, Worcester, is especially connected. Its purpose was to see whether very high altitudes might not thus be attained—higher than anything yet reached by man.

In all rockets the force of propulsion is derived from the reaction to the expulsion from the tail of burnt gases at high velocity, usually several thousand feet a second: in the case of V2 about 7,000. The oxygen required for combustion must needs be included in the fuel supply, since the flight path reaches an altitude in which the atmosphere is so tenuous as to be almost non-existent. V1 can draw the necessary oxygen from the surrounding atmosphere, V2 cannot. Professor Goddard studied thoroughly the properties of the gunpowder

rocket: others studied the use of cordite. But there is little doubt that the German plan of using liquid fuels was the best. This they tested as a propellant in an experimental automobile, using liquid oxygen and petrol as the fuel, but during the tests, car and inventor alike met with disaster.

We are told by Mr. W. G. A. Perring,* a leading authority on rocket development, that it was in 1929–30 that serious work began in Germany. Four years later the work attracted the attention of the Government, in which Hitler had just attained power, and in due course an official research station for its fuller study was set up at Peenamunda. During the following years a whole range of rockets was devised. They were known as A1 to A10, of which the fourth, A4, became in due course familiar to us and to the world as the V2. A1 was comparatively small, being only 4½ ft. long with a diameter of 1 ft. and a weight of rather over 300 lb. The A2 is said to have reached an altitude of 6,500 ft.; A3 was much larger, being about one half the size of the V2. The A4, or V2, was started in about 1940, and a couple of years later had attained a range of 170 miles. This was thought very satisfactory by the authorities, numbers were ordered, and in September 1944 the attack on Britain began. Fortunately, a few months before, a rocket experimentally fired from Germany burst in the air over Swedish territory, and the pieces recovered (about 2 tons of bits and pieces) enabled a reconstruction to be made which sufficed to show its probable size and performance; this helped in the planning of our counter-measures. Many miscarried—the first to do so fell back on its own testing station and destroyed it. A number

* A British Review of German Long-Range Rocket Development, delivered before the Royal Aeronautical Society on 1 November 1945.

of others performed in a similar way, and the work of preparation and test soon proved to be an exceedingly dangerous duty. Even when fully developed the failures remained very high—20 to 30 per cent—and of course many burst in the air when over this country.

The way in which V2's total weight of 12 to 13 tons was divided between its various parts is of interest, as it has an important bearing on the range attainable by rockets built on similar lines:—

	lb.
War head	2,200
Power unit	2,300
Equipment	600
Structure	3,900
Fuels	20,000
	29,000

It will be seen that fuel alone formed some two-thirds of the total starting weight.

The German war rocket, V2, was 46 ft. long, 5½ ft. in diameter, with a pointed nose and tail fins for steering and stability. The fuels used were alcohol (7,500 lb.) and liquid oxygen (11,000 lb.); these were pumped into the combustion chamber by a turbine driven by super-heated steam formed by mixing concentrated hydrogen peroxide and calcium permanganate solution. The whole layout of this weapon was as thorough, meticulous, and efficient as German mechanical and chemical design commonly is. It was, however, very expensive to build—costing in man-hours many times as much as V1, though it carried no more explosive, and attained no appreciably better range, nor higher accuracy in aim. It was difficult to destroy because of its high speed—but

V1 with another 50 miles an hour added to its air-speed would have been almost as immune from interception, far less costly to build and at least as effective. In fact, we see in V2 the influence of intuitive authority at its worst. Despite that intuition, and the advantage of the early start of rocket work, the higher authorities in Germany failed to insist that the range of action of the V2 should be such as to enable London to be attacked even from bases within the German homeland. With sufficient care in design it is now thought that a range of 500 miles would have been possible without any considerable departure from the general plan.

The rocket started on its course by climbing vertically, but an internal gyroscope controlling internal vanes of graphite situated in the exhaust jet stream and capable of deflecting it gradually tilted the path until at the end of the first minute of travel the angle was about 45 degrees to the horizontal. At this point the rocket motor is estimated to have been producing about 600,000 h.p., and the speed reached was, as already stated, about a mile a second, with a crest height of some 60 miles; the total range being 200 miles or more. A control unit subsequently examined at Farnborough was found to precess the controlling gyroscope in such a way as to turn the rocket nose over towards England in the following way:

Time from start in seconds	Angle from vertical in degrees
0	90
2·0	90
8·5	80
11·5	76
28·5	60
47·0	46
52·0	44

To adjust the aim of the rocket, it was at first the custom to guide its initial path by the action of a radio beam

acting on the controls, but as this proved liable to jamming, or for some other reason, it was abandoned in favour of internal control based on the speed, as determined by a highly ingenious form of integrating accelerometer (making use of the effect of gyroscopic precession). Another gyroscope was used to control the azimuth—*i.e.*, corrections to port or starboard.

Future Possible Development

It is natural to ask whether there is a risk that such rockets could be made to travel much greater distances. The answer is certainly yes, for if the warhead were replaced by a smaller rocket—say a tenth the size and weight—to be fired when its "parent" had reached its full speed, the "child" would add a further mile a second, and so reach a double speed—and therefore a quadrupled range. The range would really be more than quadrupled, since the curvature of the Earth would be in its favour. The warhead of the child would, of course, be very small—only about 200 lb. But if this process were again repeated, so that a "grandchild" resulted, the range should suffice for an Atlantic crossing. True, the warhead would then be so small as to be ineffective (at least with the explosives formerly in use) unless the parent could begin life in a vastly larger size—which would make the whole project so gigantic in cost as to be of doubtful operational utility. Nevertheless it could be done. In fact, the German authorities, looking around, no doubt, for something that would save them from the inevitable, actually tried to do this. Their experimental A10 rocket was to be a huge affair of 85 tons, of which the child was to be a V2 fitted with wings to cause it to glide on a long, sloping path through the atmosphere, and so reach a much longer range than

any hitherto known—even up to 3,000 miles, enough for an Atlantic crossing. However, the war came to an end before this monstrous weapon could be prepared.* Its threat would have been the more unpleasant because, had there been time to mature the plan, it could have been made uncomfortably accurate in aim, since much of the flight path would have been largely outside the atmosphere, and the rest of it, because of the short time of passage, little deflected by atmospheric winds or other disturbances. All that would have been required would have been to guide the initial path aright. That could have been done with considerable precision by radio methods, and since this would only be required to act during the first minute or so of flight, the intended target-country might well be so far away as to make radio jamming as a means of defence on its part quite impossible, unless some friendly radio assistance were given from a country nearer the place of origin. Thus, in case of attack on the U.S.A. from Europe, the necessary assistance could and would, of course, be given, very gladly, from Britain.

But it is fairly certain that the menace could hardly have materialized in time for use in the last war even if it had lasted a year or two longer, for the designers would, fortunately, have been bound to have had heating difficulties at the contemplated speed of over 2 miles a second. The skin temperatures would have vied with those of the surface of the sun !

That all forms of warfare must become more and more mechanized as the years passed has long been evident. That in itself need have presented no terrors to humanity,

* According to a Press statement, at present unconfirmed (*The Aeroplane*, 9 November 1945), General Arnold, Chief of the U.S. Army Air Forces, stated that America has designed a rocket similar to the V2, but with a range of 3,000 miles, and more accurate in aim. No details were given.

for the more the human body could be protected by armour and transported without strain, the fewer the casualties would be. Britain was as deeply engaged in the second World War as she was in the first, and it lasted one and a half years longer, yet the casualties among our armed forces, including the Air Force, were less than a third of what they had been in the first. And this favourable ratio is little altered even when all the civilian casualties in Britain are included. From the experience of those two wars it would have been natural to expect that the greater the extent to which machines replaced men, and the more that armour was employed to protect both, the less deadly to life would warfare become. Yet in the final months of the last war we learnt that this benevolent effect might not continue, for by the bringing into use of entirely unmanned weapons, the robots V1 and V2, there appeared the prospect of such a rise in the rate of civilian casualties as might hereafter overshadow completely the casualty rate among those in uniform. Indeed, we might have discovered this for ourselves in the winter of 1944 and the early months of 1945, had not the German time-table been thrown into confusion by the D-Day invasion, which overran their French bases, as well as by the ceaseless watch and alert action of the R.A.F. in the months before. On the other hand, it is fair to say that there are those who, with Sir George Thomson,* think that there is " little in history or logic to support the view that war waged by very powerful weapons is necessarily more destructive than war waged by the weapons they knew as boys. Wars go on till one side has had enough or in more formal language till either the will or the power to resist of one side is broken. The number of men who have to die before this happens depends little

* Lecturing in September 1945.

on the means used to kill them. . . . As to the atomic bomb destroying property, it doubtless would. But perhaps this is not wholly bad. It is as well to make it perfectly clear to the stupidest dictator that war will not pay material dividends."

It was the German aim, we are told, to despatch no fewer than 200 flying bombs every hour against London—instead of the 100 or so a day that we experienced for a few months. As it happened, this V1 effort, reduced as it was from what had been intended, dwarfed the scale of the attack by its successor, the V2, of which those despatched hardly exceeded a tenth of the flying bombs in number, whilst many failed to reach this country at all. It is true that when the rockets did arrive, they caused twice as many casualties per ton of explosive; but that was not because of any higher efficiency, but solely because, as they came faster than sound, the victims had little warning to seek shelter.

Curiously enough, there was one long-range weapon used in the last war in which accuracy in aim was completely disregarded, and that was the Japanese spherical bombing balloon. Numbers of these were despatched from Japan to drift with the wind until they, or some of them, chanced to descend on the North American Continent. They were, of course, of no military consequence whatever, but may possibly have been of some propaganda value in Japan itself.

With their devotion to the rocket idea, the Germans not only used it—as did we—for aiding the take-off of airplanes from very restricted areas, such for instance as the decks of small carrier ships; but they went so far as, in their Me. 163, to use the same idea to provide the sole means of aircraft propulsion during flight. Little, from the operational point of view, came of the

effort, since the greatest length of powered flight was measurable only in minutes, and in not very many of those; whilst gliding flight, with its restricted ability to carry out the kind of manœuvres necessary in fighting, added little to the credit side of the account. The fuel used was a combination of "T. Stoff" (hydrogen peroxide) and "C. Stoff" (hydrazine hydrate and alcohol). It was ingenious but not very useful.

One of the reasons why the "impersonality" of the robot weapon proves so troublesome a menace is that defence measures are difficult to devise. These nerveless weapons are "throw-away" devices—never to be used again. In contrast, our bombing airplanes made on the average some thirty attacks apiece before, for one reason or another, they could be used no more; and in the war against Japan the number of attacks made during the life of each bomber must have been even higher. But aircrews, being men, of whatever nationality, possess a nervous system which can be affected by the threat of gun or rocket fire from ground or air. They can in some cases be deterred by fright. Moreover, the crew has to be numerous enough to provide for the tasks of piloting and guiding, as well as defending the aircraft out and home, and so presents in the aggregate a large lethal area for attack. The flying bomb has a far smaller lethal area, and is moreover incapable of being frightened or scared from its task: on the other hand, semi-intelligent as it is, it is not intelligent enough to take avoiding action against even obvious dangers, and so is the more readily shot down either by the A.A. defence on the ground or by interceptor aircraft. Indeed, one of the mysteries of the German plan is that they should have chosen such a foolish flying speed for V1 as 300 to 350 m.p.h.; just the speed at which it could comfortably be intercepted by our faster fighters. Had they put up the

speed by as little as a fifth, it would have reduced considerably the 75 per cent casualty rate to which, in the end, they became subjected owing to our attack on them from ground and air.

To sum up, these weapons, as we have hitherto known them, are certainly capable of considerable development, both mechanically and chemically. The flying bomb can be made speedier—so speedy that no manned aircraft could catch it—and could also have a range running into thousands of miles. The rocket can theoretically have its range increased to a similar extent, putting up its speed, if need be, to 3 miles a second,* though only at a great increase in size and cost, unless some new form of fuel were available. Both can be made far more menacing by the use of more effective explosives.

It is here that the discovery of the means for releasing atomic energy opens up such dangerous possibilities. With so many urgent problems which affect human life and happiness requiring solution, it is not surprising that many people view with apprehension the prospect of having to face the complications in life which this may bring.

A curious—and endearing—feature of the British constitution is the existence of a House of Lords. But, as it happens, whenever there is a question at issue which concerns what to do, rather than how to do it, the discussions in that House are often much more illuminating than those in the Commons. This has most notably been the case in the whole field of aviation, and it seems likely that it will be so in that of the problem of defence

* The speed must not, however, be pushed too high, for a horizontal velocity of 5 miles a second would convert the missiles into tiny satellites of the Earth, destined like the components of Saturn's great system of " Rings ", to circulate for ever!

against the new weapons that the late war produced, and perhaps also against the perils inevitably accompanying the release of atomic energy. A good instance was afforded by a recent debate in that House * when Lord Brabazon, a former President of the Royal Aeronautical Society, and at one time Minister for Aircraft Production, raised the general question of the future of directed missiles and, as the phrase is, "moved for Papers". He mentioned that a previous effort, on the part of Air-Marshal Lord Trenchard, to obtain information on V1 and V2 had failed for the odd reason that the Lord Chancellor, who replied for the Government, "did not know anything about them"! However, on this occasion the Government spokesman, being an Oxford Professor, knew much, and a fruitful debate followed in which the country learnt more about the threat of the new weapons and their future potentialities than had hitherto been publicly disclosed. The debate opened with a claim on the part of Lord Brabazon that in the "early days" wars were comparatively enjoyable. "You started out surrounded by your friends, armed with swords and shields, disliking the enemy personally—whom, do not forget, you could see—and you tried to inflict as much damage upon them as you could." Wars, he explained, are not at all like that to-day, and there could be little doubt that they will be even less like it in the future—assuming that they are permitted to occur at all. The speaker thought that the scientific technique of rocket propulsion would be bound to be further developed—if only to provide for scientific research in the upper atmosphere, and perhaps for the ultra-rapid carriage of mails across the oceans. But he feared that there might be found, in some countries, those who would pursue the subject with hostile inten-

* 30 May 1945.

tion—in fact, " with revenge and hatred in their hearts ". He feared that secret preparations might be made in what were, nominally, mining shafts, but in reality underground laboratories and workshops. Such devices could be " directed against America, and if the resources in manufacturing power of a great country like America are destroyed, as they could be in twenty years' time, we must look upon the fact that we are tied up to America and if she goes, we go. Consequently this power of attack, which might be developed quietly in any part of the world, is a danger we must face."

This challenge to the Government to state its policy was answered by Lord Cherwell, then Paymaster-General, who first reminded his audience of the example of the Chevalier Bayard, *le Chevalier sans peur et sans reproche*, who treated all enemies who fell into his hands with distinguished courtesy, except only those found to be in possession of gunpowder; such dastards were instantly killed: an attitude of mind by no means rare among those long familiar with one form of weapon, and who object most strongly to the introduction of any new ones. The argument that followed ran thus. A weapon's range is not everything; its accuracy in aim is as important. Taking the Ruhr as a typical target area, only one part in twenty is built up, and less than half of that is covered with buildings; hence random fire would be of little value. It is necessary to assess not only the damage done at the particular point hit, but the chance of that point happening to be a worth-while objective. One must also take into account the effort in man-power which the production of the missile requires, and it seemed clear that the V2 compared very unfavourably with V1 in this respect; and during the last war both were at an operational disadvantage compared with the manned bomber.

In dealing with the possibility of the range of a V2 being increased to thousands of miles, Lord Cherwell showed a degree of scientific detachment which must be exceedingly rare in any atmosphere of debate, especially with the added responsibility of listening carefully to what others may say and having to state thereon the Government policy. This was so striking that the words used, as recorded by a surely astonished Hansard, are worth putting on record: "The equation of motion of a rocket is a very simple one. The acceleration is simply proportional to the momentum of the ejected gases, and the velocity with which the gases can be ejected from the rear of the rocket is determined entirely by their temperature and their molecular weight, and consequently, without raising the temperature to abnormal levels, which no material could stand, it is impossible to get the gases out at a very much greater rate than at present—something like 7,000 ft. a second. If that is so, then it is a perfectly simple calculation to show that the maximum velocity which the rocket can reach is equal to the velocity of the ejected gases multiplied by the logarithm of the total weight of the rocket over the carcass weight and the war-head; and therefore, as the range is proportional at best to the square of the initial velocity, you will not be able to put up the range very much without reducing the carcass weight and the war-head to negligible dimensions. To bring a rocket as far as New York would mean—I did a rough calculation in my head as the noble Lord was speaking—that you would have to have a total weight of fuel amounting to something well over 95 per cent of the total weight of the rocket; and, as the carcass weight of the rocket must be something, precious little is going to be left for the war-head." Whether these conclusions be accepted or not, tribute must be made to a fine display of mental arith-

metic. Those interested will find the calculation in an Appendix at the end of this book.

It was pointed out further that even if missiles with much longer ranges than any hitherto known did materialize, they would, for accuracy's sake, need to be radio-controlled, and that the radio counter-measures which would be used in defence must necessarily become more and more effective as the missiles approached the country at which they were aimed. This may be true as regards any long-range flying bomb, but scarcely so as regards the rocket. The flying bomb, in its wind-swept path, would need continuous control for the whole of its flight; but this would not apply to the long-range rocket, which in its lofty journey would travel almost wholly outside and beyond the caprice of the weather, and except for the first few minutes of its flight, when it would need to be precisely guided, it should not need further help even if its range were thousands of miles. Counter-measures to divert its path must, therefore, be initiated, if they are to be an effective means of defence, from a point not too remote from the firing-station. This would be easy in the many-isled Pacific, but hard in the bare Atlantic. If this argument is valid, it would indicate that if ever cities in America should be thus threatened from Europe, Britain, by its fortunate geographical position, might, as I have pointed out, find itself in the happy position of being able to offer America valuable and effective aid.

This debate took place some ten weeks before the first atomic bomb was used in warfare, and since all work on that subject was naturally a matter of the highest secrecy, the speaker was obliged to be silent; though few knew better than he that "precious little", to use his own phrase, would be needed of that new explosive to make an exceedingly effective war-head; whilst, looking still

farther ahead, the possible advent of an almost weightless fuel would affect even more the applicability of his ingenious calculation.

Although the energy hitherto so closely locked in the nucleus of the uranium atom can be released, there is a marked tendency for it to come in an explosive rush. If uranium is to be not merely an explosive, but also a fuel, effective control is needed in the liberation of its immense store of potential energy, so that it may emerge in a modest regulated stream, rather than in the violent detonation of the atomic bombs which brought the war in Asia to its sudden end. We seek a patient release, not a vehement one; but the exhibition of vehemence is, unfortunately, far easier to achieve than that of patience: the latter virtue is, indeed, said to be rightly sought by prayer and fasting! Years, it may be, will have to pass before this further most difficult virtue is acquired.

But even with our present knowledge, the use of uranium enables the powers of V1 and V2 to be vastly increased, certainly a thousandfold, and possibly much more. When, in due course, it is discovered how to use uranium as a fuel, the menace will be still greater, especially in the case of the rocket, which is much the more dangerous, because more accurate, weapon of the two. A rocket so armed is, indeed, likely to be "Enemy No. 1" of any World Security Organization, for batteries of them could be aligned by a predatory Power on neighbouring Capitals, and be fired without warning by some new Hitler pressing a button in his madhouse Chancellery. That must be stopped. How to do it is the problem.

*

The Defence against Robot Weapons

These new weapons may be so constructed as to be either winged or wingless. If they are winged, they are intended to fly or glide through the air, and since the atmosphere so quickly becomes attenuated as the altitude of flight increases, such devices cannot operate at any great height, and are therefore liable to be intercepted and shot down by equally fast aircraft swiftly guided to their quarry by radar. The interceptors could, if desired, also be of the robot type, flown by automatic mechanism and guided to their targets by homing devices of some sort. Such homing devices already exist—indeed, some were used during the war. " Mechanical eyes " can be made by combining certain of the features employed in television sets with those of light-sensitive cells.

When a hostile weapon itself makes this use of a mechanical eye and is self-contained, no very intelligent discrimination on its part can be expected in its choice of target, especially if appropriate defence precautions are taken inside the area under attack. If it were so designed as to be able to send back to its base a radio picture of what lies ahead, more intelligent guidance could be given to it, provided that it were within effective radio range. The country attacked could, however, always make good use of the radio counter-measures available.

Robot weapons of the V1 type can be attacked at any flying height by A.A. gun-fire from the ground, and, thanks to radar sighting, this can operate just as easily by night as by day, in clear weather or overcast, or even in the densest fog. The ranging and sighting mechanisms using radar technique are quite untroubled by atmospheric conditions. Moreover, the guns can fire shells actuated by proximity fuses, such as were used in the

defence against flying bombs attacking London, as well as against Japanese suicide planes and piloted Baka flying bombs in the Pacific. This type of fuse is described as comprising a miniature radar set no longer than a milk-bottle, carried in the nose of the shell and exploding when within some 70 ft. of the target. A time fuse is also carried to ensure the destruction of the shell before it returns to earth, should it fail to get within the desired distance of the target. We now know that it was by a combination of these means that the steadily increasing percentage of flying bombs was destroyed. No doubt future defences will be prepared with devices more accurate still; indeed, it is fairly certain that no conceivable increase in the speed or altitude of flying bombs could save them from effective attack, even though additional mechanism were added to V1 to make it weave in flight. Flying in a straight line, as hitherto, certainly makes the problem facing the defence a great deal simpler. A sinusoidal path would heighten appreciably the difficulty of interception and intensify the task, already sufficiently complex, of the A.A. gunner on the ground. The use of barrage balloons, useful as they proved during the late war, is a protection only against low-flying attack: it would be very costly in man-hours to fly them, on any scale, at altitudes much over 5,000 to 10,000 ft., whilst at such heights as 20,000 ft. or more the cost would be prohibitive. As it seems unlikely that the V1's of the future—if ever there be such—would fly as low as did those of the 1944 attack on London, defence by barrage balloons is not likely to be repeated.

Wingless weapons like V2 are much harder to destroy. They do not depend on the atmosphere to maintain their flight—indeed, their range would in most cases be increased if there were no atmosphere at all. They

reach altitudes measured in scores of miles, and no barrage balloons could hinder them. Nor, with their speeds measured in miles a second, could any defending aircraft employ interception methods against them. Their paths would, however, be faithfully and accurately recorded by radar methods, and since the trajectory of flight has quite regular and precise features, they would be liable to be destroyed by radar-sighted A.A. gunfire from the ground. Moreover, in the long run it is possible, perhaps even likely, that schemes will be devised whereby enough energy can be put into very powerful radio beams to cause vital mechanical interference with the missile whilst in flight, either diverting it from its path or destroying it altogether.

These methods of defence would, of course, be aided by air and other forms of attack on the bases from which the missiles were sent, and upon the supply lines which provisioned them. Long-range rockets, to be accurate in aim, would find radio guidance essential during the first hundred or so miles of flight, and this form of control could be jammed, or misdirected, from defence stations not too far away from the hostile bases of operation.

On the whole, it seems likely that strong methods of defence can and will be devised against all these weapons, though in the first phases of a future struggle a good many would no doubt succeed in "penetrating the defences".

It has been publicly stated that the British and Australian Governments are to join in the creation of a Rocket Defence Research Station in Central Australia. This, if true, seems a very appropriate step, since Britain itself has not the space available, and the emptier areas in Canada are too far north for work throughout the year. If, as some fear, these devices may one day be found to be armed with the atomic explosive, or driven by

atomic fuel, the task laid on any such defence establishment might grow greatly in scale and importance.

What has been said so far relates almost solely to land warfare. It has been stated in the Press that the American Government intends to carry out attacks by atomic bombs on certain discarded warships as targets. Much will no doubt be learnt from this experiment, and future naval policy will be affected thereby, though we do not know at present in what way. In any event, we may be sure that rockets will enter much more largely into naval policy than they have hitherto. Batteries of rockets are so much lighter to carry than batteries of guns that, if equal consistency in trajectory can be attained, they are likely to be preferred. Proximity fuses are also sure to come under close study. It may be that the amazing change brought into naval warfare by the introduction of radar for sighting on target ships and in spotting shellbursts, will be equalled, perhaps even surpassed, by the replacement of guns by rockets. If atomic energy is also to be used, the transformation from anything known in past naval history will be great indeed.

CHAPTER III

THE SOURCE OF ATOMIC ENERGY

IN a marvellously apposite cartoon, Low shows * the tall figure of Science erect at the side of an Earth on which, with wondering gaze, crawls the tiny child, Humanity, to be offered by the outstretched hand a marble inscribed, Life or Death: "Baby play with nice ball?"

It is indeed a youthful and often therefore thoughtless world that has to face this great dilemma. But modest, even embryonic, as our civilization may be, we can draw encouragement from the reflection that the very existence of such an opportunity arises because, and only because, of the brilliant experimental genius of the scientific research workers produced by that very civilization: they it is who in our own half-completed century have learnt, under the grave pressure of world events, how to forge the key which has been found able to unlock a door, never before opened, leading not alone to the attainment of the immediate objective, but—if we will—to an age of almost limitless promise.

To undertake such locksmith's work in so intricate a mechanism as atomic structure and on the scale necessary to deflect the operations of a great war required a gigantic effort; but under the grave menace of the times this huge effort was made—and brilliantly it succeeded. Although the basic scientific principles involved in the release of atomic energy had long been known in the laboratory, the work of designing the massive complex technical apparatus necessary for doing so on a great scale called for the highest engineering skill, and the

* *Evening Standard*, 9 August 1945. See Frontispiece.

methods so devised are still a closely guarded secret. Those who know most about it are those least likely to indulge the natural curiosity of others. But from the several official reports, American, British and Canadian, which have been issued on the subject, and with the assistance of many well-informed articles in the Press, it has been possible for the public to form an intelligible picture from the variegated pieces of this jigsaw puzzle. In this way the ordinary citizen, keen to keep abreast of the latest scientific knowledge, particularly in its bearing on world affairs, has learnt the story of the chain of events that led to the great discovery of means for calling to our aid " the basic Power of the Universe "—the commanding phrase used by President Truman on the day after the first atomic bomb had been used in war. He told us that the force from which the sun drew its power had been loosed against those who brought the war to the Far East, and that although before 1939 it had been the accepted belief of scientists that it was theoretically possible to release atomic energy, nobody knew any practical method of doing it. Early in the war, before Pearl Harbour, scientific knowledge useful in war had been pooled between the U.S. and Britain, and, in the President's view, priceless help to victory had come from the arrangement. In the end, more than 125,000 people had been put to work at the atomic-bomb factories in the United States, and more than £500 millions had been spent. The greatest marvel was not the size of the enterprise, its secrecy, or its cost, but the achievement of scientific brains in putting together into a workable plan infinitely complex pieces of knowledge held by many men in different fields of service. What had been done, claimed the President, and few will contest the claim, must rank as the greatest achievement in history of organized science.

Atomic Structure

The credit for the scientific work which formed the basis of that great enterprise must be divided between many men in many countries, but its "father" may fairly be held to have been Lord Rutherford. He it was who at the end of the first World War succeeded in breaking the tiny nucleus of an atom by attacking it with even tinier particles propelled at enormous speeds. By penetrating the heart of the nitrogen nucleus with a fast-moving one of helium (the so-called "alpha particle") he converted the nitrogen into oxygen: the quantities used may have been microscopic, but this was the actual transmutation of one element into another for the first time in history.

The old idea of an "indestructible atom" had died years before, when, in 1896, Becquerel and the Curies discovered radio-activity. We now know that, far from being indestructible, uranium can slowly change into lead! And energy is given out in the process: that is important. The atomic structure is often likened to the solar system on a tiny scale: the centre, the nucleus, is the sun and the circulating electrons the planets. Using this analogy we can say that the ordinary chemical processes we have so long known affect only the planets—the sun remaining ever unchanged. Now it is the very sun of the atomic structure which is under attack. That highly energized central core came into being when the Universe was formed, and at last we know how some of the immense store of energy hitherto so securely held therein, for perhaps thousands of millions of years, can be released. It is fortunate, since we have no ambition to reverse the processes of creation, that the cases in which we can effect this release of energy are few in number, and that the locksmith's task is long and

difficult—there is little indeed to regret that it should be so, for time is needed to make adequate preparation for the new conditions of life to which this sudden expansion of knowledge must inevitably lead.

Practically the whole atomic mass is held in the tiny nucleus, and this carries a positive electric charge. The planetary electrons, be they many or few, carry negative charges, but have exceedingly little mass. Normally the sum of the negative charges on the electrons just balances the positive charge on the nucleus. This Rutherford–Bohr model of the atom is found to explain remarkably well the ordinary physical and chemical properties of matter: those properties are determined by the number and disposition of the planetary electrons, and by the amount of the electric charge on the nucleus. "The early work", in Sir Charles Darwin's words, "gave no indication of the size of the nucleus, since it could simply regard it as a point, but anticipating later results I may say that its diameter is something like a ten thousandth part of that of the whole atom, so that if you take the tip of my little finger for the nucleus the atom would be about a hundred yards in diameter. As it takes about a million atoms in a row to make a length just visible to the naked eye, you will see we are dealing with very small quantities." *

What is called the Atomic Number of an element is a measure of the electric charge on the nucleus, and therefore of the normal number of electrons circulating around it. Hydrogen, the lightest, has only one; uranium, the heaviest, as many as 92. Figures for the masses of the nuclei run higher, thus with hydrogen as unity, the atomic mass of the most common form of uranium is 238: some uranium atoms, however, have a nuclear mass of 235, and this is said to be an isotope of the

* Sir Charles Darwin, lecture in Birmingham, October 1945.

more common variety. It was Soddy and Aston who first discovered that some elements had isotopes—forms in which the nucleus could have more than one mass. The chlorine isotopes, for instance, have atomic masses of 35 and 37, most ordinary chlorine being a mixture of the two. The element uranium, most often found with an atomic mass (which in effect means a nuclear mass) of 238, has associated with it a small proportion (0·7 of 1 per cent) of an isotope with an atomic mass of 235. Both have identical " chemical " properties, but, as will presently appear, they are in other ways exceedingly unlike. The similarity from the chemical point of view makes it difficult to separate them (as are the isotopes of almost all substances) by means normally used in chemical laboratories. It was necessary instead to make use of the mass differences of the nuclei, and such processes are slow and tedious, since the proportionate differences are usually so small: although in the case of the lightest element of all, hydrogen, it is easy because the masses of its two isotopes are in the ratio of two to one, the former being the " heavy hydrogen " which is the constituent of " heavy water ".

Degree of Stability in Elements

It had long been recognized that the atomic structure of most of the elements was very stable, and only in the case of the radio-active elements did the nucleus show signs of disintegration, emitting energy and losing weight. The rate of energy emission in such instances was, however, on far too slight a scale to be of the smallest interest to engineers concerned with military projects, and no way had hitherto been known to science for speeding up the process. It seemed that if ever this power was to be made accessible, it could only be so

when the nuclear structure was far better understood than was then the case. Here it was that help was given by Rutherford, who, as I have already said, showed that helium nuclei projected at high speed could be used to change an atom of nitrogen into one of oxygen. This exciting discovery led, in 1932, to the further one by Cockcroft and Walton, that under bombardment the nucleus of the element lithium could be broken down and power liberated. Thus the transmutation of one element into another was achieved with an associated liberation of energy which was both appreciable and important, even if far less in amount than that needed in these laboratory experiments to produce the shower of bombarding particles which caused the transmutation to take place. So at that time it was far from being a self-sustaining process. Indeed, had this experiment unfortunately chanced to be of the self-propagating type—like striking a match to light a fire—the result might well have attained to dimensions exceedingly destructive.

The Useful Neutron

As there appeared to be a limit to what could be achieved by the bombardment of the nucleus by particles of light weight, the question arose whether heavier particles, such as the positively charged protons, forming part of the nucleus, could not be used instead. The difficulty was that the electric charges on both the bombarding proton and the bombarded nucleus were of similar electric sign, both being positive. Similar charges repel each other vigorously, and it was found impossible to ensure hits. When, due to the work of Chadwick in 1932, the existence was discovered of particles which, in effect, were uncharged protons, and thereon christened neutrons, the experimenter

had at last at his command a heavy missile which, since it carried no electric charge, would not suffer from the disadvantage that it would be repelled by the nucleus.

The nucleus, it is now known, is built up from a combination of sufficient numbers of protons to give the electric charge (the atomic number), together with enough neutrons to bring the nuclear mass up to the observed value (the atomic mass). Thus an atom of U.238 has 92 protons and 146 neutrons bound together in its nucleus, whilst in circulation around the nucleus, in many orbits, are 92 electrons.

The neutron missile proved to be just what was wanted, and in due time it was found possible—by Hahn and Stressmann of Berlin in 1939—to attack the nucleus so effectively as to break it up. This fission of the atom opened up an entirely new prospect. The nucleus was bound together by enormous forces, and by releasing some of them, great stores of energy became available. Einstein had predicted in 1905 that mass and energy would be found to be convertible the one with the other, and this was subsequently confirmed by experiment. Not all substances, however, were equally susceptible to this form of attack; the most promising targets were the elements of the heavy radio-active group which had long been known to be partially unstable. Radium, for instance, gave out radiation continuously, with corresponding loss of mass, even when left to itself, and no mechanical or chemical treatment to which it was subjected by ingenious experiment had the smallest effect on the rate of flow of that energy. .

In a nucleus of the lighter elements the electric charge is small and the repulsion forces are similarly small, but at the other end of the scale, where the elements are heavy—culminating in uranium, the heaviest of all—the electric forces of repulsion between the protons compete

seriously with the forces of internal attraction (due to what cause we do not yet know), and the whole atom has a low stability and may slowly break up. This is what happens in the case of the radio-active substances at the heavy end of the table of elements. It is for this reason, no doubt, that elements heavier than uranium do not exist in nature, though they can be created in the laboratory and caused to live for a space of time.

On being attacked by neutron bombardment one of the isotopes of uranium was found to behave in a very striking way. Under suitable conditions it could start a self-propagating chain-reaction by itself shooting out other neutrons, and the resulting sudden release of energy could spread with such immense rapidity as to be the core of a new explosive material, so powerful as to dwarf anything previously known. This particular isotope was, however, far less common than U.228; in normal uranium only 0·7 of 1 per cent is U.235. To get a richer proportion of U.235 requires a separation of the isotopes, and this, with atomic masses so little different, is costly and tedious. But it was found to be worth doing. The more abundant isotope (U.238) seemed on examination to offer, in the right surroundings, the possibility of a more gradual release of this energy, and so lead the way to a new and almost boundless supply of power for engineering purposes of every sort.

Now a further discovery was made. It was found by experiment that the nucleus of the U.238 atom would, under bombardment, accept a neutron, and so increase its atomic mass to 239, though this did not of course change its chemical nature: if, however, in this process the nucleus threw out an electron, its charge, and therefore atomic number, would rise to 93, and so become a different element altogether; whilst with a further electron emitted it would become what turned out to be a

most important new element with Atomic Number 94, and to this the name Plutonium was given. This new element, plutonium, could, it was found, be converted into an explosive as readily as U.235, and not being an isotope, but a separate element, could be separated from U.238 by the ordinary processes of a chemical laboratory. In the end both forms were produced in the U.S.A. Indeed, as the two atomic bombs released over Japan, at Hiroshima and at Nagasaki, were publicly stated to be of different types, it would not be a very wild guess that one was made from U.235 and the other from plutonium. We are told that in the plutonium bomb only a small part of the energy was liberated and that if all had been used it would have been 1,000 times more powerful.

Uranium is not the only heavy element capable of acting as a new source of energy. Thorium may, it is suggested, also prove suitable, and others may be found. All seem likely to be relatively rare elements, and it is perhaps fortunate (at present) that they are, for the political problems which would have to be faced if we were suddenly deluged with limitless power for war or peace might prove overwhelming. But one has also to consider the other end of the atomic table, the hydrogen end, where the atoms are light. It is not a case here of obtaining energy by fissure of the nucleus, but by the synthesis of light hydrogen atoms to make heavier ones, like helium or even nitrogen. During that process—if it can ever be effected on the earth, as we believe it is in the sun—energy will be given out even more abundantly than from uranium. It would require the use of exceedingly high temperatures, such as those in the interior of the sun; but it has been pointed out * that in the atomic

* Lord Russell (Bertrand Russell, F.R.S.) in the House of Lords, 28 November 1945.

bomb such temperatures are reached; hence it is at least conceivable that the two processes might be linked up, some day, and that, if they were, much more violent explosive bombs could be manufactured. Moreover, hydrogen is a plentiful element. But by that date we can surely expect that mankind will have learnt how to ensure that the abundant energy so liberated is used only for beneficent purposes. No other purpose may indeed then seem conceivable.

The tremendous engineering effort and the correspondingly huge expenditure which this work required did not daunt the American Government. How considerable it was can be learnt from the report published in America in August 1945 giving an "Account of the Development of Methods of using Atomic Energy for Military Purposes under the Auspices of the United States Government, 1940–1945" written by Dr. H. D. Smyth. Fortunately it has been reprinted in this country by the Stationery Office, and so is generally available. It is a most dramatic story of a great pioneering venture very effectively told, though somewhat technical for the lay reader. In the course of it Dr. Smyth warns us that if a "power-pile" could be built to have an output of 1,000,000 k.w., it might be expected to produce as a by-product about one kilogram of plutonium a day. Whether a technique will some day be devised for producing the useful power without the production of the explosion producing plutonium, we cannot at present tell. But more will be said about this in later pages.

Controlling the Energy Flow

For certain applications it is necessary that one should be able to lessen the rate at which the energy is released by the use of some slowing-down or moderating

medium. Fortunately such mediums have been discovered. One is heavy water, the compound of heavy hydrogen with oxygen, and another that form of carbon known as graphite. It was this possible use of heavy water which led to our action, during the war, in destroying the German-held supplies in Norway. That dramatic action arose from the determination, as Darwin put it, to prevent the enemy from climbing a step on the ladder which we had already passed some time before. No doubt other moderators will be found. Graphite, being easily obtainable, is the material so far preferred. The metal Cadmium is also of use, as it absorbs neutrons readily, and can therefore be used as a sort of control switch to regulate the rate of the flow of power. This lends itself to a convenient thermostatic form of control.

When in 1940 it became clear that a new explosive of immense power could be produced for war purposes, it was foreseen that a single bomb so armed might prove as powerful as many thousands of tons of the types hitherto used, an expectation fully borne out by the event. It was characteristic of the new explosive that the mass used must be of a certain size: not too small, and not too large. If too small, the energy-releasing neutrons could escape from the surface without performing their task, and if too large, the mass would disintegrate on explosion into fragments too small to continue to be effective: although in the latter case there would certainly be an explosion, it would not be proportionate to the quantity used; hence it would be better divided up in the first instance, and used in smaller masses.

To start an explosion all that was required was to bring together two of the masses, each too small to sustain a chain reaction by itself, but fully able to do so when brought into contact. The temperatures reached

in the ensuing very violent reaction might reach millions of degrees, and the pressures hundreds of thousands of tons per square inch. Such a mighty effect had never been known on Earth since man inhabited the planet, though it had long been thought that it might well occur in the life-history of some of the stars.

We are told that it was in November 1941 that the American experts advised their Government that by exerting very great effort it should prove possible to release atomic energy in a way effective for war purposes within three or four years from that date. This remarkable forecast proved the wisdom of those that made it, for the time interval from November 1941 to August 1945 was just that predicted.

Production for War and Peace

That, in brief outline, is the scientific story of the building up of our knowledge of the structure of the atom and of its utilization in time of war to produce the deadliest weapon of all wars. Its application to this end by the Allied Powers was undertaken in America, Britain and Canada (in alphabetical if not chronological order). Most of the work—especially that of later years—was done in North America, being freer than Britain from the risk of interference by enemy action. In Montreal a joint British–Canadian research establishment was set up, and a gradual transfer to North America of the scientific staff hitherto working in Britain led to the closing down of all work here on the electro-magnetic separation of isotopes, so useful for separating U.235 and U.238, and a great lessening, for the time being, of all work on nuclear physics. It was certainly a wise decision, for it led to the most rapid possible development, free from interference, of the atomic bomb.

It was soon realized that the difficult and tedious work of separating U.235 and U.238 could be effected by one of two methods: that of the mass-spectrograph by streaming atoms through a powerful magnetic field so as to bend the path of the lighter ones through a larger angle than the heavier; and that of separation by the process of diffusion or evaporation. But the element plutonium, being a different element and not an isotope, could be readily separated from uranium by ordinary chemical means. It was decided to produce both in a parallel effort.

The result of this immense scientific and engineering enterprise was vividly pictured by Mr. Churchill in the House of Commons: * "On July 17 there came the eagerly awaited news of the trial of the atomic bomb in the Mexican desert. Success beyond all dreams crowned this sombre magnificent venture of our American allies. Detailed reports of the Mexican desert experiment, which were brought to us a few days later by air, could leave no doubt in the minds of the very few who were informed that we were in the presence of a new factor in human affairs and were possessed of powers which were irresistible. The decision to use the atomic bomb was taken by President Truman and myself at Potsdam, and we approved the military plans to unchain the dread pent-up forces. From that moment our outlook on the future was transformed. Marshal Stalin was informed by President Truman that we contemplated using an explosive of incomparable power against Japan, and action proceeded in the way we all know now. It is to this atomic bomb more than to any other factor that we may ascribe the sudden and speedy ending of the war against Japan."

Only two bombs had to be dropped before the end

* 16 August 1945.

came—one over Hiroshima on 6 August, the other over Nagasaki a few days later. The saving in Allied lives by making unnecessary the purposed invasion of Japan by millions of troops must have been enormous. In Mr. Churchill's view the invasion casualties might well have included a million American lives and a quarter of a million British; besides, no doubt, even greater numbers of Japanese. The actual loss of life in Hiroshima and Nagasaki was small in comparison.

Some critics have thought that it would have been more humane to have made the first attack on some uninhabited part of Japan—as an object lesson to the Japanese authorities of the new overwhelming power now in the hands of the Allies. But the Military Command thought otherwise (perhaps they found it difficult to believe that the scientists' bombs would really be so much more effective than those already in use).

From the observations made in the New Mexico experiments it seemed that much of the destructive action of the bomb was due to the intensely powerful heat rays radiating from the explosion—a true "death ray", in fact. (That bomb was exploded just above the surface of the ground, and the temperatures reached were so high that the sandy soil for half a mile was turned into glassy lumps.) With bombs exploded at a low level, the radio-activation of the ground might be not only considerable, but persistent, and this would be unnecessarily harmful to all animal and vegetable life. It was for that reason that the attack on Japan was made by bombs set to explode high above the ground.

To protect those in the manufacturing works from the harmful effects of the radio-activity produced by the products of fission, elaborate precautions and means to watch their effectiveness were necessary. One was the use of pocket meters, about the size of a fountain pen,

which could be examined each day to indicate the amount of radiation to which the wearer had been subjected. It became the practice to issue two of these to all who entered a dangerous area, and to read them on entry and on leaving. Another precaution was to instal at the exit gates of certain laboratories concealed devices which would sound an alarm when anyone passed whose clothing, skin or hair had become affected. Members of the staff who suffered hurt were given other duties or sent on vacation or otherwise treated. None, we are told, showed permanent effects.

In the two chief production plants, at Hanford, Washington, and at Oak Ridge, Tennessee (the latter on a reservation of no less than 59,000 acres), the workers were numbered by tens of thousands. Of the raw material required for the work—the uranium-bearing ore—Canada is a leading producer, and there is said to be a fairly wide, if somewhat scanty, distribution throughout the world. In 1940 the U.S.A. import of this ore are stated to have been 1,250 tons, but what it was in later years is not revealed. Useful deposits occur in Australia.

In all this great enterprise Canada took a large share. The joint Canadian and British laboratory set up in Montreal had a staff of over 340—the largest organization ever created in Canada to carry out a single research project. It was closely co-ordinated with the work in the United States, and a construction plant was built at Petawa, Ontario, using uranium from the Great Bear Lake deposits—the second largest known source in the world—which have now been taken over by the Canadian Government. As the Petawa plant aimed at the production of power under control, it used a slow neutron reaction, with heavy water as moderator. Some of the neutrons are not slowed, and these produce plutonium as a by-

product. The heat of the reaction is absorbed by rapidly flowing water or gas. The metal surface temperatures were, at the time, too low for this heat to be used effectively for the generation of power, but this it is hoped to change by further work. From time to time the uranium metal is removed from the plant and the plutonium extracted chemically. This plant can supply also radioactive materials for the study of chemical and biological processes and for application in medicine.

The Power-Pile

Once some way has been found of preventing the world from ever indulging in the warlike use of the atomic bomb—an essential prerequisite—the path will be free for the rapid development of means for reaping the immense advantage of the use of atomic energy for purposes having a purely economic and beneficent character. In its technical aspect the path is now clear for the difficult but not impossible task of designing Power-Piles, as such new types of power plant are called. The first of such Power-Piles was built in Chicago in 1942, but it was not thought safe to take from it more than a fraction of a kilowatt. Two years later knowledge had grown and, at the Clinton Works in the Tennessee Valley, the output was raised to over a thousand kilowatts. The first Pile is reported to have contained five tons of uranium metal (obtained by electrolysing uranium tetrafluoride) surrounded by graphite bricks and pressed uranium oxide. The intensity of the reaction was controlled by varying the position of a number of cadmium rods which could slide in slots; cadmium having the virtue of readily absorbing neutrons. The resulting flow of heat energy could be absorbed by water—thus perhaps one day replacing existing steam

boilers with apparatus much more compact—or even by heating air for use in turbines of the kind now being introduced for aircraft propulsion. Given that the cost of the new fuel be not too high, its first employment will no doubt be in electric power-stations, especially those located close to the chemical works where the fuel is prepared. An essential step towards these practical developments is the finding of a good anti-corrosive sheathing for the uranium rods. This sheathing has to meet a difficult specification representing the needs of the physicist and the engineer. Aluminium was the first choice, but beryllium, for instance, would be far better provided it could be produced in malleable form.

In its purely military application the heat produced during the manufacture of the explosive was a by-product of the process: in the civil use, however, it may well be that plutonium will prove to be a by-product from the production of the desired heat energy. If that should be so, it will need careful watching and some arrangements to be made for such a potentially explosive material to be handled correctly both in the physical and the political sense. As has already been said, as much as a kilogram of plutonium per day may be produced when the power output is a million kilowatts.

The amount of atomic energy capable of being tapped has been expressed in many ways. Einstein showed that the amount of energy, E, produced by the annihilation of a mass, M, was given by the relation

$$E = MC^2$$

where C is the velocity of light.

This when expressed in numbers leads to startling results. It shows that 1 kilogram (2·2 lb.) of matter, if converted entirely into energy, would produce 25,000 million kilowatt hours of energy, equal, as the U.S.

Report puts it, to the total generated by all the electric power-stations in America in two months' running. This amazing performance contrasts with the eight or nine kilowatt-hours produced by burning an equal weight of coal!

The position has been put equally graphically by the President of the Institution of Electrical Engineers,* who, looking on the matter from a British power engineer's standpoint, considers that: "On a theoretical computation, one ounce of matter transformed entirely into heat energy would convert a million tons of water into steam. If the whole of the matter were converted, it would only require a mass of one pound to generate over ten thousand million kilowatt-hours, at 100 per cent efficiency, so that the whole of the Central Electricity Board's system could be supplied for a year by converting into electrical energy a mass of four pounds. It is interesting to compare this with the mountain of coal consumed in one month by only one of the many power stations supplying the grid."

Professor M. E. Oliphant, of Birmingham University, in estimating its effectiveness as an explosive, calculates that a lump of these materials, smaller than a rugby football, would have the equivalent explosive force of 20,000 tons of T.N.T., and that before long bombs could be made with an explosive force of a million tons, and later, if desired, of even ten times as much.

Looking back on this great enterprise and on its dramatic issue—6 August 1945 is now one of history's leading dates—and not less on the grave problems which we have now to face, it seems that there was some justification for the writer ending his Presidential Address on "The Future of Flying", to the Engineering Section

* Mr. P. Dunsheath's Presidential Address to the Institution of Electrical Engineers, 4 October 1945.

of the British Association three days before the second World War began, with these words: " We may be very content to leave to our successors the menace of dealing aright with the problem of atomic energy . . . in a recent address Professor Cockcroft spoke of an atomic trigger action between the metal uranium and a single neutron which is reported to be capable of releasing a 100 millionfold increase in energy. Perhaps there are immense practical difficulties in doing this on a large scale; I earnestly hope there are! For ourselves we may well consider that in our own day we are quite sufficiently occupied with the thoughtful handling of our own special problem, how rightly to guide the future of flying." Yet, under the immense stimulus of the war, Allied scientists solved the problem of the military use of this store of energy within five years! The grave question of how to handle it rightly is now urgently before us.

Whether the methods employed for the preparation of this new explosive could, in the nature of the case, be kept for long as a secret, and whether its manufacture could and should be controlled by some extra-national authority, are left for discussion in a later chapter.

The British Government has, as already mentioned, appointed an Advisory Committee on Atomic Energy, under the chairmanship of Sir John Anderson. In addition to official members, it includes scientific representation in Sir Henry Dale, Professor P. M. S. Blackett, Sir James Chadwick, and Sir George Thomson. This Committee is at work and has, it is easy to believe, an ample agenda. It has research facilities at the Atomic Energy Research Station near Didcot, under the direction of Prof. G. B. Cockcroft, a former worker with Lord Rutherford at the Cavendish Laboratory, Cambridge.

CHAPTER IV

POSSIBILITIES OF INDUSTRIAL AND ECONOMIC DEVELOPMENT

We have been able to discuss the use for warlike purposes of atomic energy in some detail since a good deal of practical knowledge has already been attained, not a vast amount, perhaps, but enough to act as a signpost to what next may be expected to happen if events are left to follow their own course. It is harder to write of the possible civilian uses of the new source of power, since so little at present is known, and even what there is has been very guardedly revealed. Nevertheless, the engineering and economic possibilities are so immense and so important that if public opinion is to form itself, or even to make a beginning in doing so, the facts, so far as they are known, need to be collected and discussed so that their bearing on the coming years may be made evident.

Although this new source of power offers opportunity for a dangerous extension of what are called "Power Politics"—a danger to be discussed in later pages—certain precautions can be taken, as will be there indicated. In this chapter, which deals with the civilian use, such caution respecting possible lines of development will happily be unnecessary. It is natural to ask at this stage how far these two aspects can be effectively separated. Could the equipment for industrial use be turned instantly to the purposes of war? Could his real intention be so camouflaged by a potential aggressor as to appear to be a normal peaceful and lawful activity?

One must frankly admit that at this early stage it is impossible to say. Some of the research workers concerned in the development of atomic power give the answer as "yes", others make equally public a contrary view. So far as one can judge, the best opinion at the moment is that there is likely to be a sufficient difference in production technique to render such a conversion in purpose difficult to effect. It will be fortunate if, in the end, that proves to be so.

Since the liberation of atomic energy appears to require a mass of material above a certain size or amount for the process to work, it is likely—in the first instance, at any rate—that its initial application will be in large electric generating stations as an alternative to the use of coal, oil or water power. Although the new material is expensive it is consumed so slowly that it may be able to compete easily with the use of coal; in which case we in Britain will rejoice in the prospect of replacing an underground, and therefore unpleasant, occupation with one above ground and under more easily controlled conditions. This will be the more welcome, since staff for the pits is increasingly hard to recruit and is likely to become even harder when the work of mining is forced to lower and lower depths in the earth in order to find workable seams. Our own coal-mine owners may indeed awake to discover that they are, after all, being bought out by the State at just about the right time for them—an example, perhaps, of the difficulty which any Cabinet with the usual amount of scientific acumen must face when it pursues some programme path of economic expropriation.

It will no doubt be simplest to plan that the power-stations which make use of this new source of energy shall—in the first instance, at least—be located in the vicinity of the chemical works where the material will be made

Although the fission of the atom could in theory lead to so intense a flow of energy that huge temperatures would be reached, running to millions of degrees (the temperature at the surface of the Sun being less than ten thousand), in practice the energy flow will be kept low, so that at the working point the temperature shall not exceed what the materials—usually metals—will stand. Means for doing this are known—at least in principle. It remains to be seen whether it will be best to use this energy to produce steam for existing turbines—so displacing the huge batteries of boilers, and the labour of feeding them —or, possibly, to work internal combustion turbines of the type now coming into extensive use in aircraft.

According to one scientific authority,* things are already moving quickly; production costs were "tumbling", and he was confident that within ten years we should have power-stations working under the new power. "We had to go ahead in Britain with the development of the military and economic uses of nuclear energy. We could not leave it to America. We must be prepared to spend money and effort, and it might cost £100 millions spread over the next ten years to carry out this development."

Much the best way of distributing power in this country is by the electric grid. The channels along which it flows are already there, and they are capable of easy extension where necessary. Supplies can often be obtained at a fraction of a penny a unit, of which a part is fuel cost. By reducing that portion in amount, the cost to the user would be lessened and the demand would grow. That demand would grow in any case, to reap the advantage, now increasingly sought, of having more self-working apparatus in the home. But coal is

* *The Times*, Prof. M. E. Oliphant, on 17 September 1945.

unfortunately an increasingly expensive source of power, and any alternative to it is very welcome. Coal deep in the earth is one of Nature's free issues; as, for that matter, is water power, and even the energy stored in the atom. The cost of any of these arises in getting them to the place where we can use them. In this respect some countries are better placed than others. Some have no coal but have plentiful oil—like the Middle East. Others have little coal but abundant water power—like Switzerland, Italy and Norway. Others have no such facilities at all; and it is to them that atomic energy offers at least the possibility of redress. How far this new energy must needs be used at, or near to, the place of its origin remains to be seen. But as the atomic bombs released in August 1945 were made in America and used in Japan, export appears to be possible. If the new fuel were sufficiently plentiful and could be exported as readily as is coal, the problem of the fuelless areas of the world could easily be met—for the tonnage to be moved would be very small in proportion to the number of thermal units available. Even if the "containers" were bulky, the weight of fuel to be carried being measured in pounds, or even ounces, instead of tons, the shipping costs should be little. Moreover, any thick concrete walls for the protection of staff could easily be provided locally.

There are parts of Australia, remote from supplies of coal, oil or water power, which would benefit greatly by irrigation once they could get it. Although there are hardly any great rivers, underground water in very large quantities is often available, though not infrequently at so great a depth below the surface as to require an immense effort for pumping. Australia * has, as it happens,

* Professor Griffith Taylor: "Australia" (Methuen & Co.).

the largest artesian basin to be found anywhere in the world: strictly speaking a well is described as "artesian" only if the water rises naturally to the surface; "sub-artesian" is the better adjective to use where the supply has to be assisted by pumping. But in common usage the word "artesian" covers both types.

The "Great Artesian Basin" in Australia certainly deserves the attribute "great", since it is no less than 1,270 miles long from north to south and 900 miles wide from east to west, with an area estimated at 600,000 square miles. The depth from the surface of the ground to the water level is, however, considerable, often 1,000 feet and sometimes as much as 7,000 (in which case the water arrives boiling). Of this area of 600,000 square miles, 400,000 are in Queensland, 100,000 in New South Wales, and 100,000 in South Australia and the Territory. It is stated that the wells already sunk have doubled stock-raising capacity; but little or no arable use has been made of the supply, as all is needed for sheep and cattle. Moreover, the water from the lower depths often contains salts of one sort or another. Professor Griffith Taylor adds that although by 1937 over 1,200 square miles in Australia had received the benefit of irrigation, this amount is less than one-thousandth part of the total area of the Continent. How far the benefits of irrigation could be extended, given sufficiently cheap power for pumping, is a matter for determination by expert opinion. If, as seems certain, there is plenty of room for such development, the possibility of cheap fuel from atomic energy becoming one day available is well worth attention.

Before the war the amount of electric power produced annually by the leading countries was (in millions of kilowatt-hours):

U.S.A.	116,000
Germany	55,000
U.S.S.R.	36,000
Great Britain	31,000
Japan	26,000
Canada	26,000
France	15,000

and in the whole world about 420,000. In proportion to population, Canada led the world, using at least ten times the average per head for the rest.

Britain is still at the beginning of her era of electric-power utilization, but even so uses five times as much per head as the world average. Hence the world could use five times as much as it does now even to reach our present level. Countries, to be high on the list at present, need to have conveniently accessible coal-mines, oil-wells or water-power, but, as has been said, with atomic energy the quantities of raw material required are so small that transport difficulties almost vanish, and there appears little reason why an abundant supply of electric power should not become available in any place where it is needed: a "Niagara Falls" everywhere. The effect of this on irrigation projects, and therefore on the world's all too scanty supply of food, can hardly be exaggerated. Many areas sadly lack an adequate source of power.

According to *The Times*,* the high annual increase of population in India calls for a yearly addition of no less than 1,000,000 tons of food. "Particularly hopeful for the immediate increase of the Indian food supply are the projects for organizing regional authorities on the model of the T.V.A. in the United States . . . it is now clear that the expansion of irrigation in India, so far from having exhausted its possibilities, constitutes a

* 28 September 1945.

chief instrument for the drive to raise the living standards of the masses which is the foundation of economic planning." The taking of the T.V.A. scheme as a model is very striking, but natural; there, it is true, water-power was potentially abundant—that it was so was no doubt one of the chief reasons for the choice of that particular area for the great experiment. Before that decision was taken the Tennessee Valley had been a depressed area, lagging far behind the national standard on almost any method of estimation. Now, with power abundant and cheap,* the population is larger and happier. Its homes are equipped with the many electric facilities that make leisure hours, even for the housewife, no longer an unattainable dream. The President, in his Message to Congress in September last,† urged that similar projects should be undertaken for the development of the Columbia, Missouri and Arkansas Rivers and for the Central Valley of California.

The stress on Valley areas is notable. It is important, too, in its bearing on our present discussion. Valleys are chosen first because, with an adequate rainfall, the surrounding hills and mountains provide lakes and water-falls, with areas that can easily be made into storage reservoirs, and so provide the power necessary for the economic development. But there are other areas, immense in extent, equally hungry for power. A supply which is not dependent on the chance of some happy arrangement of the geological formation of the country, must greatly add to the existing opportunities for the development of land not at present capable of economic utilization.

* Power to the extent of over 2 million kW is available, at the cost of only 2 cents per kW-hour for the 5,000 million sold in 1941.

† *Nature*, 22 September 1945.

Granted that electric power-stations are likely to be the first beneficiaries, the next development may well prove to be the great ship with its huge steam turbines; how far down the scale in size it will be possible to go has yet to be revealed, but railway locomotives and large aircraft are prospective possible users. Although the smallest size in which a power-pile can be made is uncertain, and is likely to remain so for some time, it is encouraging that one group of the American investigators should have reported, as long ago as 1941, that they envisaged the possibility of small chain-reaction units for power production weighing as little as 100 lb.

If an almost weightless fuel were some day available for a transatlantic air-liner, the pay-load on present designs could, it is estimated, be trebled. With a three-fold increase in income, a substantially higher price for fuel could, if necessary, be met; whilst if the fuel were available at the same cost as before, a substantial reduction in fares could be effected, so increasing the numbers of the public able to enjoy the advantage of rapid travel by the airways of the world.

CHAPTER V

THE NEED FOR CONTROL

WHAT is at stake is the happiness and well-being of the entire human race. In Mr. Churchill's grave words: "This revelation of the secrets of nature, long mercifully withheld from man, should arouse the most solemn reflections in the mind and conscience of every human being capable of comprehension. We must, indeed, pray that these awful agencies will be made to conduce to peace among the nations, and that instead of wreaking measureless havoc upon the entire globe they may become a perennial fountain of world prosperity."

It is an unfortunate human experience that knowledge seems always to travel faster than the wisdom that should guide it. That we do gradually learn, as a result of sheer hard work and painstaking effort, to acquire new controls over Nature is no doubt a credit to our brains, but that we use so badly those powers when we have them shows that our ethical standards do not keep pace. Aviation is a child of the very century in which we live, but it is sadly true that many more aircraft have been built for the purposes of war than for civil use.

The art of using atomic energy, our latest achievement, is now in its very infancy, but the first sound from its baby cradle is the roar of an explosion! If our race is to eschew mass-suicide, some form of control over this new power must be devised, and quickly. Those who regard such fears as alarmist form their opinion perhaps on the fact that our Prime Minister of thirteen years ago

predicted in the House of Commons * that the "next war"—that just ended—would "wipe out" European civilization. But grave indeed as have been the injuries inflicted, not only in Europe but in many other parts of the world, civilization, though sorely hurt, has not been "wiped out"—not even in the European cockpit. People have proved themselves remarkably resilient against even the terrible air bombing from which so many have suffered. But now that the menace has been increased many thousand-fold, and may yet increase further, the powers of human endurance might well be strained beyond the limit in any future struggle. This time we must end war itself.

Mankind is like a child having in its grasp for the first time a very sharp knife. What the child will do with it will depend on his character and disposition, and even more on his maturity. If very young, he may well do himself, and his fellows, mortal harm—unwitting of his own unwisdom. Is such a child more immature than mankind itself? Sir James Jeans thinks not, for he tells us how exceedingly youthful is the entire human race. Comparing the age of the Earth with the height of the Nelson Column, the years of man's existence would be no more than the thickness of a coin and his few thousand years of civilization that of a postage stamp. There is little of maturity there. As to character and disposition, we have lately seen how little there was to prevent the rise of the Nazi type. Potential Hitlers probably still exist. Some day, it may be, eugenic control of population will minimize, or even prevent, the birth of such misfits: our present *laisser faire* procedure, if followed by racehorse breeders, would bring them to speedy ruin.

This time, providentially, we have escaped, though

* Mr. Baldwin, 10 November 1932.

the new tools that helped us can, without wisdom, create their own peril. And however lacking in maturity we may be, we ought surely to possess enough confidence in ourselves not to look to Providence to come to our aid every time that we get into trouble. The most loving father thinks it wise to let his children essay the management of their own affairs once they are past infancy. And we are growing out of infancy: city States have emerged into the groups we call nations, and now it is for nations to group themselves, for certain vital purposes at least, into a world organization. To the latter end the heartening first step was taken at San Francisco.

A first requirement of any all-embracing World Security Council, such as San Francisco devised, would be to control the use of the new weapons. No nation, unless acting as Trustee for the United Nations, would be allowed to prepare or construct such devices; and it would be the duty of the Security Council to keep meticulous watch that no such effort could escape detection. Mr. Churchill has told us that the Canadian Government has already undertaken new surveys and explorations in search of uranium ores, which, on discovery, will be Government-controlled, and ultimately used under whatever arrangements are made for controlling the release of atomic energy in the interest of mankind. The United States Government has taken similar steps.

The Security Council

The common hope of people to-day for the preservation of the peace of the world lies in the controlling power of the above-mentioned Security Council, as part of "The United Nations" Organization created at San Francisco in June 1945. The first step towards this much-

sought end was taken at a meeting in London four years before, when representatives of fourteen nations gathered around Britain, as the leader in the fight against Nazi Germany (neither U.S.A. nor U.S.S.R. being then in the war). That gallant core of resistance resolved that " the only true basis of enduring peace is the willing co-operation of free peoples in a world in which, relieved of the menace of aggression, all may enjoy economic and social security; and that it is their intention to work together, and with other free peoples, both in peace and war to this end ". Later in that same year came the Atlantic Charter, followed two years later by the Moscow Declarations, and then by the carefully devised Dumbarton Oaks plan. These manifold activities paved the way for the San Francisco Conference in the succeeding April, which faced the immense task of preparing a World Charter acceptable to all. The Charter finally agreed upon has the merit that, unlike the old League of Nations, it provides that if peace is unable to be preserved by consultation and mediation, it shall be maintained by force of arms; the Scales of Justice, as Sir W. Beveridge once said in the House of Commons, are of little avail without her Sword.

It is laid down in the Charter that the Security Council should consist of eleven members of the United Nations, of which five (U.S.A., Britain, U.S.S.R., France and China) should be permanent members and the other six * elected by the General Assembly from the other forty-five countries represented. To " maintain international peace and security " the United Nations undertakes to make available to the Security Council, on call, such armed forces and other facilities, including " rights of passage ", as may be necessary to that end. Further,

* Australia, Brazil, Egypt, Mexico, Netherlands and Poland were chosen.

that, in order to enable the United Nations to take urgent military measures, member States are required to hold immediately available national air-force contingents for combined "international enforcement action", the strength and readiness of these contingents, and of plans for any combined action required, being determined by the Security Council with the assistance of a Committee comprising the Chiefs of Staff of what have become known as the "Big Five" Powers.

It was, however, provided in the Charter, somewhat to the dismay of the more thorough-going idealists, that the enforcement of peace by military means should only be taken if and when all of the "Big Five" Powers agreed. Each of these Five has at present, therefore, the power of veto. It may indeed be objected that although by the Charter these Five can prevent any of the forty-five signatories from going to war, there is nothing in it to prevent any individual one of the Five from making war at any time on any other State. That is true. But it was also true at the time the Charter was drafted, which was just before the atomic bomb appeared, that if any serious rift should occur between the Five, nothing written on paper, not even the present Charter, could ensure peace. Events would take their course, and another World War might result. On the other hand, great fires can be caused by small flames, and it is a real gain that in the Charter we are given some assurance that these little flames can be extinguished before they have time to spread. In some cases purely local action might suffice, and the Charter provides that nothing shall impair the inherent right of individual, or collective, self-defence if an armed attack is made on any Member State, until such time as the Security Council can take the measures necessary to maintain peace. Local action thus taken in self-defence

has to be reported at once to the Council, but it is laid down that such action shall not limit in any way the authority and responsibility of the Council to pursue its own action in its own way to the end that peace and security shall be restored. In brief, the Charter provides an Assembly for discussion and a Security Council for action. The Council will have the task of standing sentinel (but, unlike the old League of Nations, a sentinel armed) and of maintaining continuous watch on world events. If it sees anything untoward happening, it can urge conciliatory action on the States concerned before the dispute becomes menacing. It can offer arbitration. If these steps fail to produce a settlement, it can advise other Member States to exert economic pressure on the recalcitrant governments, and in the last resort (likely to be rare) call on other States to apply military measures. If it desires, it can take very swift action itself by use of the Air Force contingents at its constant disposal. In all such measures it will have the benefit of the advice of its Military Staff Committee, comprising the Chiefs of Staff of U.S.A., Britain, Russia, France and China. But as it stands at present no military measures can be put into force unless those five Powers are unanimous. That is the drastic power of the present " veto ". Perhaps the ordinary man-in-the-street may wonder why it should be given to a country with so little military aptitude as China (unable to resist aggression by a State with a far smaller population). He may, indeed, wonder why the members ever grew from Three to Five, and, if the reason was a sentimental regard for those who had suffered much, whether this was quite the best way to give effect to that feeling. In other respects, the existence of the veto reveals what was, at the time, a realistic attitude to world organization, and to that it is hard to object; though it may be harder to avoid the fear

lest the veto, so long as it lasts, should be used on occasion for bargaining, or even as a lever.

Such are the powers invested in the Security Council by the Charter. They go at least some way to meet the need lately expressed * by Field-Marshal Smuts: "This war has taught us that idealism is not enough and that we cannot get away from the problem of power. That is where this greatest war in history had its origin. We have found that all our idealism, all our high aspirations for a better world and a better human society, stand no ghost of a chance unless we reckon with this fundamental factor, and keep power well in our minds when we search for a solution of the problem of security. The question of power remains fundamental and it is, I think, the great lesson of this war. Peace unbacked by power remains a dream."

To sum up, a Security Council has been created. It has been provided with immense power; in the phrase of the day, "it has teeth". Its duty is to stand sentinel in some selected centre—preferably, perhaps, in the United States—and there keep vigilant watch on world events. If ever the preservation of peace appears to be threatened, it will call on the countries concerned in the dispute to settle their troubles by conciliation or arbitration. If that fails it can apply the moral pressure which its paramount position so readily enables it to bring to bear; should that, in turn, fail, it can call on other Member States to apply economic pressure; and in the last resort—which is likely to be seldom—it can make use, under the expert direction of its Military Committee, of the armed forces which the Charter provides.

It happens, fortunately, that (for the present at any rate) huge apparatus, and workshops to match, are

* Address to Empire Parliamentary Association, 25 November 1943.

requisite for the construction of atomic bombs. President Truman estimates that those built in the U S.A. for use in the war cost the huge sum of £500 million sterling. So long as that is the scale of things, it should not be difficult to detect any attempt by a bandit Power to build such weapons; once detected, by the radio-activity of the atmosphere in the neighbourhood of the factory and testing ground, or in other ways, they could easily be destroyed by any flight of ordinary bombers, or even better—as causing less accessory damage—by landing troops from troop-carrying aircraft. Resolute paratroops would make short work of any such banditry and be a mode of deterrent action more agreeable to days of peace. But more drastic means would lie in the background.

It has been tacitly assumed in the above argument that such a bandit Power would not be hindered in its aggressive action by any lack of knowledge of the technique of manufacturing atomic weapons, whether for use as bombs or as sheer radiation. How far is that true? On that point many opinions have been expressed by responsible authorities. This variety of view is chiefly, if not entirely, due to the different standpoints of the men expressing them. A theoretical physicist, knowing that the basic knowledge, such as we have, of atomic constitution was world-wide, might naturally conclude that any idea of secrecy must be absurd and might say so with emphasis; but an engineer might claim just as emphatically that there was a world of difference between knowing a theory and putting it into practice, and that the gap in time between the two was often very great. Motive power from steam was known as a possibility 2,000 years ago, and was only effectively put to use last century.

So far as our present problem is concerned, America, Britain and Canada now share the knowledge of what to

do and how to do it: should this painfully won knowledge be broadcast, or should it not? Would there be any sane purpose in telling everyone the best way to construct weapons likely to be banned to national armament? If it is hard to decide, there is at least a middle path which has much in its favour, which is that the bomb-making technique should be kept secret until such time as the Security Council has won universal support and confidence. The question could then be further considered. But that middle view is by no means universally held. Some idealistic writers have insisted that it should be released at once, and to all. To them the searching question may be put, Had this very same question of open publicity arisen in 1938 instead of 1945, would they have advised its communication to all, including Germany and Japan? And if it had been, what would have been the likely consequence in the 1939–45 war?

No one will, however, it is to be hoped, seek to prevent research workers in Universities and the like from pursuing their great task of widening the bounds of knowledge and making their discoveries public through the usual scientific channels. On this a President of the Royal Society has written: * "I believe, further, that the abandonment of any national claim to secrecy about scientific discoveries must be a pre-requisite for any kind of international control, such as will obviously be indispensable if we are to use atomic energy to its full value and avoid the final disaster which its misuse might bring. If it be objected that this would be incompatible with military secrecy of any kind, I should be bold enough to ask whether that is not already useless. If armaments are to be used only for the international policing of aggressors, what use have we for national

* Sir Henry Dale in *The Times*, 8 August 1945.

secrecy ? "—a challenging question. If national armies of millions of men are outmoded, they must not be replaced by hostile masses of scientific workers. Or to quote Lord Cherwell : * " The thing we must try to avoid is an arms race in making atomic bombs ; but is the best way to prevent a race to get all the competitors lined up level behind the starting gate ? Nothing, I should have thought, could be more calculated to produce the very thing we wish to avoid. . . . I am often told that scientists are like people who have put a box of matches into the hands of a wilful and ignorant child. That may be, but is the remedy to make sure that every child in the party has just as good a box of matches as its neighbour ? "

It appears that in the considered view of the American Government the secret details of the manufacture of the atomic bomb, however temporary that secrecy may be, should not be prematurely divulged. This view has also been expressed by Mr. Churchill : † " He was in entire agreement with the President of the United States that the secrets of the atomic bomb should as far as possible not be imparted at the present time to any other country in the world. That was in no design or wish for arbitrary power, but for the common safety of the world. . . . The United States stood at this moment at the summit of the world. He rejoiced that that should be so. Let them act up to the level of their power and their responsibility, not for themselves, but for all men in all lands, and then a brighter day might dawn upon human history. So far as was known there were at least three or perhaps four years before the concrete progress made in the United States could be overtaken." This opinion was also supported, at a meeting ‡ of the United

* House of Lords, 16 October 1945.
† House of Commons, 16 August 1945.
‡ Oxford, 8 October 1945.

Nations Association, by Sir Arthur Salter: he did not accept the view that because it might be thought "intolerable" for the secret to be the permanent monopoly of one country, or of a few countries, it should be immediately divulged to all.

The last word in such a discussion must rest with America, and what that is likely to be is plainly indicated in an important speech made by President Truman (27 October, 1945): "The atomic bomb does not alter the basic foreign policy of the United States. It means that we must be prepared to approach international problems with greater speed, with greater determination, and with greater ingenuity, in order to meet a situation for which there is no precedent. We must find the answer to the problems created by the release of atomic energy—as we must find the answers to the many other problems of peace—in partnership with all the peoples of the United Nations. Discussion of the atomic bomb with Great Britain and Canada and later with other nations cannot wait upon the formal organization of the United Nations. These discussions, looking forward toward a free exchange of fundamental scientific information, will be begun in the near future. But I emphasize again, as I have before, that these discussions will not be concerned with the processes of manufacturing the atomic bomb or any other instruments of war. In our possession of this weapon, as in our possession of other new weapons, there is no threat to any nation. The possession in our hands of this new power of destruction we regard as a sacred trust. Because of our love of peace, the thoughtful people of the world know that that trust will not be violated, that it will be faithfully executed. Indeed, the highest hope of the American peoples is that world co-operation for peace will soon reach such a state of perfection that atomic methods of

destruction can be definitely and effectively outlawed for ever."

The possession of this knowledge places a grave responsibility, in the President's words a Trust, on its possessors to ensure that, for whatever space of time they remain alone among the nations of the world to be so equipped, they must do their utmost to ensure that everything practicable is done to create an atmosphere in which it will be possible to entrust it to the Security Council, with the assured condition that all countries will give that Council (without any question of veto by any one) the right of supervision and inspection in all territories everywhere, with power to send its inspectors where it will. The effort to get complete agreement for such a plan may fail, but it should be attempted, and a real effort made while the knowledge is still secret, even though it may mean that the United Nations Charter, as at present laid down, will require to be somewhat amended to meet the new conditions which have arisen with such suddenness since the San Francisco Conference.

A most important step has since been taken by the Governments of the United States, of Britain and of Canada. At a meeting in Washington in November 1945 the American President and the Prime Ministers of Britain and Canada, issued a "Three-Power Statement on Atomic Energy", and this, in view of its great call to all the nations of the world, is reproduced in an Appendix following this chapter.

It proposes to ban from national armaments the entire use of atomic weapons. If that proposition were agreed, the troublesome question of broadcasting any secrets concerning the manufacturing processes necessary for making such bombs would disappear, as being redundant. On the other hand, all useful information relating to the production of atomic energy, for what the Three-Power

Statement defines as " industrial and humanitarian purposes ", would be given by every nation possessing it the widest possible publicity.

To pursue this plan with the highest speed and effectiveness, it proposed that there should be set up a Commission to prepare recommendations on these lines for submission to the United Nations * for their consideration and, if agreed, for their adoption. But it must be a pre-requisite condition that all nations agree to the elimination of the atomic bomb from their armaments: that weapon, if used in future at all, would be used by the Security Council only, as a means for carrying out its task of maintaining peace and order throughout the world.

The Security Council solution, involving as it does the ultimate surrender to a new extra-national organization of the supervision of a whole branch of technical activity (but leaving the Universities free to continue their task of scientific investigation), is sure to excite misgiving among those who cling to every aspect of national sovereignty. But the change to some degree of world organization is one to which we are driven by events. Small States, as we have seen during the past decade, are quite unable to preserve their rights when their greater neighbours are at war; their status as completely sovereign entities, during such times, is a hindrance to their neighbours' powers of defence, and in the end a grave menace to their own existence. " The release of atomic energy, now an accomplished fact, can ", Sir Henry Dale warns us, " either destroy civilization or immensely enrich its possibilities; the choice is clearly before mankind and those who guide

* The Assembly of the United Nations set up, in January 1946, a Commission on Atomic Energy, to consist of representatives of those States on the Security Council together with Canada. This Commission will work under that Council so far as concerns all matters touching security.

its destinies. It is everybody's concern and the statesman's supreme responsibility."

Is there any alternative to such a world-wide plan? Could, for instance, the Anglo-American world act alone if the rest of the world failed to agree? The answer is certainly yes, but the degree of security would suffer. And in the improbable event that even this limited action should prove not possible, could the British Commonwealth act alone? Again the answer is yes, though rather more doubtfully, for the degree of security attained, though welcome, would be far from complete; schemes that extend to only a part of the world, though better than nothing—very much better than nothing—cannot give us what we really require. The only solution which can ultimately satisfy the world's needs is a World Security Organization having at its command appropriate means, if it desires them, for constructing atomic explosives or other weapons to aid it in the security service it will give to all, as part of what would be in certain respects a form of World Government. No solution short of this can fully meet the urgency of the situation which the enterprise of scientists and engineers has created. Need statesmanship—in any country—lag behind the needs of this increasingly scientific age? Must it be so purblind as to leave the world exposed to alarm and doubt, and to that irrational state of fear which leads so easily to insensate action?

The administration of these matters may, it is true, prove difficult owing to their technical complexity. But technical affairs, even if complex, can be understood at the cost of some trouble; though naturally they are more easily followed by those who have sympathy with the scientific attitude to life. Perhaps this is due, in part, to the reluctance of rulers anywhere to equip themselves with a sufficient measure of scientific know-

ledge. But if the world is to be wisely guided in the conditions which exist to-day, a change is necessary. If those in authority find the road hard, may they not be asked, with great respect, to give way to those who would not ?

With the banning by U.N.O. of the use of atomic explosives in national armies, the necessary supplementary action would be :

(1) The supervision by the Security Council of the United Nations (acting perhaps through a Trustee Power, such as the U.S.A.), free from any sort of " veto ", of all experimental stations and factories (and of all substances produced therein) which, in its opinion, are capable of being used for the production of atomic explosive materials.

(2) The equipment of that Council with such scientific and technical staff, as well as apparatus, as are necessary to enable it to carry out the above task, and to provide the necessary intelligence and inspection services to ensure that the Council shall be advised betimes of any infringement of these regulations.

(3) The placing upon that Council of the duty to assist in every possible way in the development of atomic energy as a source of useful power, so that its discovery shall " conduce to peace among the nations and . . . become a perennial fountain of world prosperity ".

We need hardly be in doubt as to the policy likely to be followed by our own Government. It was forecast in general terms by Sir Stafford Cripps * (at the launching of the aircraft carrier H.M.S. *Hercules* on 23 September 1945): " We must do two things: first,

* *The Times*, 24 September 1945.

we must remove the opportunities for quarrels. That might not be wholly possible, for we could not change mass human nature any more than we could change individual human nature. However good an organization for eliminating disputes we might devise, we should still have international disputes in the future. Nobody looking at the condition of the world to-day, with its widely differing stages of economic, social, and political development, could doubt that there would be many occasions ahead which, in spite of all we could do to prevent them, would result in serious international differences. We must, then, as a second step, devise a means whereby those differences could be settled without war, however much they might involve the national honour of countries. There could be no exception if we were to maintain human life and civilization.

"This most urgent matter surpassed all others in importance. We might have a few years in which the atomic bomb was not a common weapon in the hands of all major Powers, but they would be pitifully few in view of the immense task confronting us. This was a matter which must be taken up by everyone, and not merely by a few overworked statesmen. The driving power must come from the common men and women all over the world."

It is indeed imperative that the ordinary citizen everywhere shall exert whatever power or influence he may have to ensure that a right judgment is reached on this great issue, so vital to the future of himself and his fellows. The material collected in these pages will, I hope, help him to do so. But so many aspects of life and work are concerned that no one writer would care to claim expert knowledge on more than a small portion of this immense field.

The opinion of so eminent a scientific leader as Professor Albert Einstein, the originator of the theory of

relativity, in such matters as are under discussion in these pages must be given weight. In his view * the secret of the atomic bomb should be divulged neither to the Russian Government, nor to any other, nor even to the United Nations Organization, but should await the creation of an integrated World Government, to which it should be freely imparted. In urging that we should all go the whole way towards a World Government, and not merely a part of the way, as in the United Nations Organization, he claims to be a realist and not the dreamer that it might be expected the protagonist of such a scheme would be. In his view the end sought must prove unattainable by half-measures. To make a present of the atomic bomb either to the Soviet or to United Nations would, he suggests, be like the action of a capitalist who, seeking a partner, should proceed at once to divide his capital with him, so running the risk that the partner might then use the cash to start a rival business! The three great Powers (America, Britain and Russia) are asked to charge themselves with the formation of a single Government to which they would then pass the whole of their armed forces. Others could join in. Professor Einstein is frank to admit that he has some fears of tyranny resulting from such a centralization of control, but he dreads still more the danger of another war.

There is at least one other way in which a central World Authority could be recognized, perhaps with less difficulty than Professor Einstein's. Mr. Churchill described America as now at " the summit of the world ", and he was manifestly happy that that should be so. America is without imperialist ambition. She desires to see the world enjoy the " Four Freedoms " stated by her late President. We do so, too, and so presumably

* *Daily Telegraph*, 29 October 1945.

does the Soviet Union. Can the U.S.A. be trusted at all times to be truly altruistic? And would she accept the duty of being Trustee for all? Her power is unrivalled, and so it is likely to remain. Would it quite certainly always be a power for good for everyone? These are some of the searching questions that have to be faced. Those who would reply to them in the affirmative are perhaps accepting some risk. Is it too great?

To deal with the manifold moral issues involved would indeed be a hard task: fortunately, some to whom we naturally look for guidance in such matters have spoken out boldly both in Press and Pulpit. The Archbishop of Canterbury * expresses himself as less fearful of this new discovery leading to "endless destruction", than that it may too soon increase the ease of human life, for: "Great comfort is a temptation more dangerous than great danger. To use the increased leisure and to use it fruitfully will call for an increase in man's own spiritual resources. Men must become better men."

The ideal has been described as a point to which one can always draw nearer, but never reach. It is the human intention that counts for righteousness. As a wise man once said: To believe in the reform of human society may be an act of faith, but to believe in it without a change of heart is an act of lunacy.

We face a great moral challenge, the kind of challenge implicit always when we win new powers which can be turned to good or ill account. Meet it we must. The path before us may call for humility of soul; for a cleansing of hearts, everywhere, from pride, vain glory and hypocrisy—and—not least—from all unworthy national ambitions.

* *Time*, 20 August 1945.

APPENDIX A

THE THREE-POWER STATEMENT ON ATOMIC ENERGY *

" THE President of the United States, the Prime Minister of the United Kingdom, and the Prime Minister of Canada have issued the following statement:

"1.—We recognize that the application of recent scientific discoveries to the methods and practice of war has placed at the disposal of mankind means of destruction hitherto unknown, against which there can be no adequate military defence, and in the employment of which no single nation can in fact have a monopoly.

" 2.—We desire to emphasize that the responsibility for devising means to ensure that the new discoveries shall be used for the benefit of mankind, instead of as a means of destruction, rests not on our nations alone, but upon the whole civilized world. Nevertheless, the progress that we have made in the development and use of atomic energy demands that we take an initiative in the matter, and we have accordingly met together to consider the possibility of international action:

> " (*a*) To prevent the use of atomic energy for destructive purposes.
>
> " (*b*) To promote the use of recent and future advances in scientific knowledge, particularly in the utilization of atomic energy, for peaceful and humanitarian ends.

" 3.—We are aware that the only complete protection for the civilized world from the destructive use of scien-

* *The Times*, 16 November 1945.

tific knowledge lies in the prevention of war. No system of safeguards that can be devised will of itself provide an effective guarantee against production of atomic weapons by a nation bent on aggression, particularly since the military exploitation of atomic energy depends, in large part, upon the same weapons and processes as would be required for industrial uses. Nor can we ignore the possibility of the development of other methods or of new methods of warfare, which may constitute as great a threat to civilization as the military use of atomic energy.

"4.—Representing, as we do, the three countries which possess the knowledge essential to the use of atomic energy, we declare at the outset our willingness, as a first contribution, to proceed with the exchange of fundamental scientific information; and the interchange of scientists and scientific literature for peaceful ends with any nation that will fully reciprocate.

"5.—We believe that the fruits of scientific research should be made available to all nations, and that freedom of investigation and free interchange of ideas are essential to the progress of knowledge. In pursuance of this policy, the basic scientific information essential to the development of atomic energy for peaceful purposes has already been made available to the world. It is our intention that all further information of this character that may become available from time to time shall be similarly treated. We trust that other nations will adopt the same policy, thereby creating an atmosphere of reciprocal confidence in which political agreement and co-operation will flourish.

Industrial Uses

"6.—We have considered the question of the disclosure of detailed information concerning the practical

industrial application of atomic energy. The military exploitation of atomic energy depends, in large part, upon the same methods and processes as would be required for industrial uses. We are not convinced that the spreading of the specialized information regarding the practical application of atomic energy, before it is possible to devise effective, reciprocal, and enforceable safeguards acceptable to all nations, would contribute to a constructive solution of the problem of the atomic bomb. On the contrary we think it might have the opposite effect. We are, however, prepared to share, on a reciprocal basis with other of the United Nations, detailed information concerning the practical industrial application of atomic energy just as soon as effective enforceable safeguards against its use for destructive purposes can be devised.

"7.—In order to attain the most effective means of entirely eliminating the use of atomic energy for destructive purposes and promoting its widest use for industrial and humanitarian purposes, we are of the opinion that at the earliest practicable date a Commission should be set up under the United Nations to prepare recommendations for submission to the organization. The Commission should be instructed to proceed with the utmost dispatch and should be authorized to submit recommendations from time to time dealing with separate phases of its work.

"In particular, the Commission should make specific proposals:

> "(*a*) For extending between all nations the exchange of basic scientific information for peaceful ends.
>
> "(*b*) For control of atomic energy to the extent necessary to ensure its use only for peaceful purposes.
>
> "(*c*) For the elimination from national armaments

of atomic weapons and of all other major weapons adaptable to mass destruction.

" (*d*) For effective safeguards by way of inspection and other means to protect complying States against the hazards of violations and evasions.

" 8.—The work of the Commission should proceed by separate stages, the successful completion of each of which will develop the necessary confidence of the world before the next stage is undertaken. Specifically, it is considered that the Commission might well devote its attention first to the wide exchange of scientists and scientific information, and as a second stage to the development of full knowledge concerning natural resources of raw materials.

" 9.—Faced with the terrible realities of the application of science to destruction, every nation will realize more urgently than before the overwhelming need to maintain the rule of law among nations and to banish the scourge of war from the earth. This can only be brought about by giving wholehearted support to the United Nations organization, and by consolidating and extending its authority, thus creating conditions of mutual trust in which all peoples will be free to devote themselves to the arts of peace. It is our firm resolve to work without reservation to achieve these ends."

APPENDIX B

ROCKET RANGES

THE calculation of rocket range is in some ways rather simpler than that for a gun projectile, but in other ways less so. It is simpler in that most of the rocket path lies in so tenuous an atmosphere that the resistance, which depends on air density as well as speed, is almost negligible. It is quite appreciable, of course, in the lower layers of the atmosphere, but at a height of 15 miles it is as little as 3 per cent of its sea-level value; and since with the V2 rocket only about a seventh of the total time of flight is spent below that level, the trajectory as a whole does not depart much from that of an unresisted projectile. The calculation tends, however, to be more complex for the rocket than it is for the shell, in that whilst the latter reaches its full velocity on leaving the muzzle of the gun, the former rises steadily in speed whilst the fuel is being consumed during the early part of the flight (in the case of V2 the fuel takes about a minute to burn in a total time of flight of 5 minutes).

For a shell fired in a non-resisting medium with a muzzle velocity of V feet per second, the maximum range is obtained when the elevation of the gun is 45 deg. above the horizontal, and its range is then equal to V^2/g, where g is the usual gravitational constant; and the height reached is $V^2/4g$—*i.e.*, exactly one quarter of the range.

With a rocket burning its fuel at a constant rate and ejecting it steadily, the maximum velocity obtained, in a non-resisting medium, is given by the expression

$$V = A \log \frac{W}{W - F}$$

where A is the speed of ejection of the gases, W the starting weight of the rocket and F the initial weight of the fuel. This no doubt was the formula used by Lord Cherwell (see p. 29).

The calculation of range is more difficult in the case of the rocket, since it may be so great that the effect of the curvature of the Earth has to be allowed for. If, in the first instance, one ignores this correction, then the rocket range is very much the same as that of a shell of equal crest speed—and proportional to the square of that speed. Thus a rocket like V2, with a speed of 1 mile a second, would have a computed range of about 165 miles from the point of maximum speed. It actually covers a greater total distance, because one must add the length of its path whilst the fuel is being burnt at the beginning of the flight, and the corresponding length at the end. So that the total range would come to about 200 miles. If the speed were doubled, the range would be rather more than quadrupled.

One can compute also for higher speeds, though one must remember that when the range grows to 1,000 miles or more, the effect of the Earth's curvature is considerable, much to the advantage of the range: until at 5 miles a second the rocket would be travelling too fast ever to return to the Earth, and would circulate as a new satellite. Our present satellite, the Moon, being far off, is able to maintain its distance at a speed of little over one half of that of the V2 rocket.

Although computation shows that a speed of 3 miles a second would easily suffice for an Atlantic crossing, such a speed would be difficult to attain in practice, and be even harder to provide for in the design of the warhead, since the "stagnation temperature" at the nose of the rocket would rise rapidly with the speed, being roughly equal to the square of the ratio which that speed

bears to 100 m.p.h. Thus at 3 miles a second, or some 10,000 m.p.h., this temperature would run to about 10,000 deg. Cent., which is well above that of the surface temperature of the sun; no convenient temperature for the casing of any explosive! Moreover, although the atmospheric temperature falls rapidly for the first 7 miles of ascent, at much greater heights it increases considerably, owing to the more intense penetration of solar radiation. This also will add to the temperature attained by the rocket.

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